MINERALS
IN
MODERN INDUSTRY

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MODERN INDUSTRY

BY

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PREFACE

The arms of commerce now reach so far, railroad and steamship lines that give rapid and easy transportation are spread so broadly, and diffusion of knowledge takes place so quickly that trade can not be local except in those commodities which supply only local needs, which are produced only in small quantities, or which are of small value compared to their bulk. These remarks apply to the mineral industries. A study of modern industrial production will show how greatly is our material prosperity and our high standard of living dependent upon a far-flung trade in minerals, and how even the United States, richest of all nations in material endowment, is not self-contained in its mineral needs.

In this volume the author aims to present the fundamental economic facts and characteristics relating to the mineral industry. The technical phases of mining, ore dressing, and metallurgy are discussed in the many works available on these subjects and are treated here only to an extent that is considered essential in understanding the economic aspects of the production of minerals and metals.

The subject is treated from the point of view of the United States and, necessarily, the economic characteristics of the mineral industry in foreign countries are touched upon only briefly or omitted altogether. In the case of those minerals which move extensively in international trade and in which this country has a vital interest, world conditions are discussed.

The author wishes to acknowledge his indebtedness to Dr. C. K. Leith of the University of Wisconsin, in whose graduate class in economic geology his interest was awakened in the important relation of minerals to the industrial structure. He is also grateful for the suggestions of the graduate students in the Mineral Industries Course given by the author at the University of Pennsylvania from 1926 to 1930.

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CHAPTER I

THE MINERAL FOUNDATIONS OF INDUSTRY

THIS mode of living, this present culture, which we humans choose to call the industrial era, stands unique in history and apart from previous epochs in the extensive and rapidly changing aspects of its economic life. The outstanding characteristic of this age is the wide application of machinery and the use of power. We find ourselves in the midst of an industrial civilization which has removed physical limitations and reduced manual burdens. Man's productive powers are increased and the material goods at his disposal and for his enjoyment have been augmented. The significance of this age lies not, however, in the fact of increase as such, but rather in releasing man from a dependence upon his own muscular efforts. In the last analysis the astounding changes that have been wrought are due to the introduction of the power machine as a substitute for animal muscle, for this includes everything that has come to this generation through the steam engine, the dynamo, the automobile, the airplane, the telephone, and the radio. When James Watt, in 1775, brought the steam engine into practical use, he laid the foundations upon which the industrial structure was created. In the words of Hendrik Willem van Loon, "It was on that day that man ceased to be a beast of burden and was given the first chance to become a human being."[1]

While the steam engine is not the first effort to reduce physical labor, it certainly is an important event in the transfer of toil from man to the machine. Modern technology, whether it be mechanical, electrical, or chemical, differs from the first crude steam engine in refinement, in efficiency, and in adaptability to various kinds of work, but it still retains that original characteristic—to produce more with less effort, to transfer more work from the muscle of man to the machine until, to-day, the workman is approaching the position of a director of harnessed energy.

[1] Whither Mankind, by Chas. A. Beard, et al., p. 43.

The utilization and control of mechanical and electrical power on so large a scale necessitated also a science to serve as a guide to the management of men. The effectiveness of machine production depends upon an intelligently directed coordination of men, machines, and materials, i.e., the science of management. The earliest important contribution to a science of directing human energy was by Frederick W. Taylor, who applied the scientific method of measurement to tasks and approached the problem of wages and incentives in the same manner. Since Taylor, Gantt, Barth, Emerson, the Gilbreths, and many others have contributed to this scientific achievement of the twentieth century.

The modern outcome of this development of the machine is the growing importance of the manufacturing industries. For manufacturing not only enters into the task of preparing in usable form the essentials of life—food and clothing; it also engages in the task of making the additional comforts and luxuries enjoyed by so many human beings. This is significant for, when man's activities were confined toward satisfying the bare needs of existence, the main attention was centered in agriculture and on food preparation. When, however, the machine entered and attention was directed more and more toward providing additional material comforts, demands on production rose to heights never dreamed of, and the manufacturing equipment to supply and anticipate these wants increased faster than agricultural activities. This increase is reflected in the upward curve of production of manufacturing raw materials—rubber, lumber, paper and, most important of all, the metals and minerals.

The metals have been responsible, in no small measure, for the discovery and colonization of continents. "Gold rushes" into lands previously unoccupied have culminated in the political and economic expansion of the Americas and Africa. The gold production of these countries, it is true, is but a small fraction of the wealth now obtained from their pastoral and agricultural products, but the precious metals constituted the bait with which the fish were caught.

Metals have been used since early times for simple implements and weapons, but it was not until the industrial revolution in Great Britain that the mechanization of industries led to any considerable development of mineral resources, first slowly and with a limited range of products, then on a large scale and with an extended variety. The outstanding feature of the use of metals in the modern age is not the newness of the use of these elements, but rather the ever-accelerating quantity used and the ever-widening application of their uses. Coal is mined in small quantities in the eighteenth century; it grows appreciably in the early decades of the nineteenth century; and, since 1900, more coal is extracted out of the earth than in all previous world's history. The production curves for iron, copper, lead, and zinc tell similar stories.

If the growth, as well as the origin, of the industrial revolution is due to the close association of suitable minerals, the transportation factor gave added impetus to the movement. We have been told in the classroom of the remarkable series of inventors who laid the foundations of the textile industries in the north of England, and of the timely invention of the steam engine and its application to mine pumping; the successive construction of the steamer and the locomotive; and the production of gas from coal. But the close association of ore, fuel, and flux made it possible not only to improve machinery but also to increase facilities for the transportation of raw materials and their products.

As industrial technique became more complex, more refined, and exact, other metals with peculiarly distinctive properties appeared on the scene. Aluminum, though a late comer, experienced a startling rise to world attention. Obscure metals became indispensable as alloying ingredients of steel. When, in 1888, Sir Robert Hadfield produced his special manganese-steel, he opened the way for the production of other ferro-alloys and so extended the requirements in commercial quantities of metals which were previously of interest only in the laboratory—vanadium, tungsten, molybdenum, chromium, cobalt, and nickel. The adoption of alloys, especially the ferro-alloys, at the end of the last century opened up a new period in the newly established mineral era of the world's history, for, besides the increase in the quantity of the base metals which were wanted for industrial growth, it was necessary to look further afield for supplies of those metals that had hitherto been regarded as rare in quantity and nominal in value. Other relationships may be cited. Precious metals, like platinum, find a key use in scientific research and in the chemical industries. Sulphur ranks with metallic iron in the diversity of its industrial applications. The world demands more food, hence the phosphates, potash, and nitrates bulk large in the commodities of commerce. Man longs for comforts of many kinds—the machine makes their production possible; the minerals supply the raw materials. Ushered in with the industrial era is the "Third Kingdom," the kingdom of minerals.

What have been the scientific discoveries, inventions, technological advances, or historical events which have conspired to usher in the modern machine age? The search for the beginning of an idea usually leads far back of the date of the invention, and it is difficult to place an historic finger on the individual who originated an idea. We know that the Egyptians, in the period from 4000 to 1000 B.C., possessed bronze tools which included straight and circular saws, solid and core drills, hammers, and axes for drilling stone.[2] Their achievements as workers in stone were limited by the materials and tools they possessed. In a later century (the third century, B.C.) Archimedes made an important contribution to the science of mechanics by the invention of the screw pump. Previous to his time, water was raised by buckets operated by hand for irrigation and domestic use. His was an important contribution as it involved an analysis of the screw. He was also the first to formulate the principle of buoyancy.

Perhaps the next important contribution was made by Galileo, who represents the real beginning of modern science. It was he who taught his contemporaries and successors the formulation of laws through a patient and unbiased observation of a large number of particular facts. The birth of the science of mechanics dates from Archimedes, but its adolescence lasted over fifteen hundred years. Its renaissance was accompanied by a galaxy of contributors, chief of whom were Galileo, Newton, Kepler, Huyghens, Descartes, and Maxwell. Boyle, Hooke, and Gilbert all added to the refinement of physics. We shall select, for illustration, only a few of the discoveries, inventions, and events in mining history contributing to the movement that flowered in the machine age.

The scientific discoveries in the field of physics and chemistry, especially during the early part of the nineteenth century, paved the way for those inventions which followed one another in quick succession. In 1767 James Hargreaves, an English spinner, invented the spinning jenny, which enabled a single workman to spin eight or ten threads at once, and thus to do the work of as many hand spinners. A year later Richard Arkwright patented a device for drawing out threads by means of rollers. In 1779 Samuel Crompton made a happy combination of Hargreave's spinning jenny and Arkwright's roller machine, which was called the mule. Before the end of the eighteenth century, power-driven machines spinning two hundred threads simultaneously had been perfected.

The enormous output of thread and yarn in these new machines made the weavers dissatisfied with the hand looms, which had been little changed for many centuries. At length, in 1784, Cartwright invented a new loom which automatically threw the shuttle—the forerunner of the modern loom. Other inventions followed. In 1792 Eli Whitney, in the United States, invented the cotton gin which, as it was improved, enabled one man to take the seeds out of one thousand pounds of cotton

[2] Science, n. s., Vol. LXXI, No. 1829, Jan. 17, 1930, p. 58.

a day instead of five or six pounds, which had been the limit of the hand worker.

The effect of these inventions in increasing the amount of cloth manufactured was astonishing. In 1764 England imported only four million pounds of raw cotton, but by 1840 she was using nearly five hundred million pounds.

The increase of textile manufacturing depended, however, upon two elements—a strong material out of which the machines could be built, and power to motivate them. The first was supplied by the timely development of the iron furnace, the second by the practical application of the steam engine. Although iron had been used for tools, weapons and armor for hundreds of years, the processes of reducing iron from the ore and working it up were very crude. It was not until 1750 that coal was used for smelting the ore instead of charcoal. The old-fashioned bellows gave way to iron furnaces, and steam hammers replaced the hand in shaping the metal.

Watt's steam engine opened the door for the application of power to machinery. Although the steam engine was invented by Newcomen many years before, Watt was able to make it a practical machine for furnishing power to the new factories. In 1785 the steam engine was first applied to run spinning machinery in a factory at Nottinghamshire. Arkwright adopted it in 1790 and by the end of the century steam engines were becoming as common as wind and water mills.

More direct, in their influence on the mineral industries, however, were the metallurgical and electrical discoveries and inventions. As early as 1746 the principle of the electrical condenser was discovered in the invention of the Leyden jar. Franklin, pursuing the studies of the electrical experimentalists of that day, modified the Leyden jar and built the prototype of the modern electrical condenser. His was the beginning of those historical experiments with moving electricity which were destined to have such far-reaching and practical consequences. The electrical currents of Franklin, accomplished by connecting the two sets of electrically charged plates with a conducting wire, produced an electrical current of only momentary duration. Motion of large quantities of electricity over a continued period became the object of scientific investigators. The momentary current in the Leyden jar is due to a temporary difference of potential between the inside and the outside of the jar. To produce a continuous electrical current through a conductor, a continuous difference of potential must be maintained between its terminals. This may be accomplished by a thermo-couple, by mechanical means, or by the action of chemical energy, and it was by using the means of chemical action that Volta, in 1800, discovered an electrical generator which produced motion of electrical charges much greater and more easily managed than the Leyden jar or electrical condenser. The voltaic cell, an electrical generator of ideal simplicity, was the achievement of the researches of Gray, Franklin, and Volta, and the significant contribution at the end of the eighteenth century. The path of progress moving toward the electrical age was next carried on by Oersted. Working with the electrical currents produced by voltaic batteries, Oersted discovered that electricity in motion produced magnetic lines of force in every portion of space. This discovery laid the foundation of electro magnetism, of which applications are seen in the generators and motors and electrical measuring instruments, the transformers, and the telegraph instruments of the present day. Within a week after Oersted announced his discovery, that brilliant French physicist, Ampere, translated the law of its behavior. The discovery of the magnetic effects of the electrical current needed only the arrival of Faraday to see the reciprocal relationship between the electric current and the magnetic field, so that just as the motion of electricity produces magnetic force, so the motion of magnetism produces an electrical current. Faraday's epoch-making studies of these phenomena paved the way for the construction of the first crude dynamo (1831) and formed the basis upon which his electrical successors brought about the most spectacular changes in industry and society.

While these events were occurring in the electrical field, the science of metal utilization was going forward. The cementation and crucible processes of making steel, known to the ancients, were rediscovered in Belgium (1606) and England (1742) respectively, and remained the sole methods of steel manufacture until Henry Bessemer gave to the world in 1856 the famous process which now bears his name. He announced his discovery in a paper before the British Association for the Advancement of Science entitled "The Manufacture of Malleable Iron and Steel without Fuel." By 1870 Bessemer steel exceeded other methods in output; also 1870 and the decade following marked an expansion of the steel industry hitherto unknown and marked the beginning of the greatest industrial development the world has seen. The first Bessemer converter may well be placed beside the first steam engine as marking one of the important events in ushering in the age of the machine. For, without cheap steel, the harnessing and directing of power to machinery would have been severely handicapped indeed. The ever-increasing demand for steel, which even the phenomenal success of the Bessemer converter could not satisfy entirely, soon led to the development of the open-hearth process in 1858. While not as rapid nor as prolific a producer as the Bessemer process, and far less spectacular, the open-hearth method can handle ores with a higher phosphorus content. The acid Bessemer was always handicapped because pig iron with less than 0.1 per cent of phosphorus was necessary. The majority of ores, in this country at least, carry more than this amount. The basic Bessemer requires pig iron containing not less than 2 per cent of phosphorus. The vast quantities of material which contains percentages of phosphorus between these limits are useless so far as the Bessemer converter is concerned. The open hearth, although, growing in use slowly, finally equaled Bessemer in 1907 and now supplies 80 per cent of domestic steel.

The cumulative effect of scientific research, stimulated no doubt by demands of an ever-expanding industrial era, in the late nineteenth century, gave to the world the alternating current generator, vulcanization of rubber, manufacture of coke, the Goodyear welt, the Otto engine, the arc and incandescent lamps, electric steel, the Owens bottling machine, the steam turbine, aluminum reduction, chrome tannage, portland cement, and the birth of the automobile industry.

Coincident with the fruitful era of industrial technology is the development in the field of transportation. In 1827 the Baltimore and Ohio Railroad Company was chartered—the first railroad company in the United States. Twelve years later the railroad mileage was 4000. The development of industrial machinery in the closing decades of the nineteenth century was paralleled in the transportation field by the Pullman car, Westinghouse air-brake, refrigerator car, the stock car, and the automatic coupler. It was like the advance of a battle line, each unit supporting and making possible the advance of another, in a line of units of complex and diverse functions.

The rise of industry, carrying with it an unprecedented demand for metals and minerals, also made itself felt in the mining industry. Probably the most significant development is the introduction of the diamond and churn drills in prospecting for ore bodies. Before drilling as a means of exploring for ores was introduced, only outcrops of ore or geological probabilities indicated where "pay dirt" might be found. The only methods of determining its actual presence was by opening up a mine, at high cost, and then failures were frequent. The use of the drill revolutionized prospecting. By means of it, deposits of irregular outline and depth can be blocked out and the metal content, grade, and chemical composition of the ore determined. The low-grade disseminated porphyry coppers, for example, which added so much to the world's visible supply of copper were uncovered, only because well-conducted drilling campaigns have been adopted which permitted the mining companies to erect reduction works to treat the forthcoming ore.

Equally remarkable in its influence on ore recovery and the extension of ore reserves is the development in the treatment of ores by flotation and leaching.

In the flotation process of ore treatment, the ores are ground to fineness, and the metal-bearing ores are separated from the waste material by capturing and floating in a froth or film of oil on a water bath. The essential economic contribution of the flotation method is to effect a more complete separation of the valuable ores from the gangue and also to permit the profitable working of leaner ores than were possible by the water-separation method.

Leaching of ores, also a means of recovering minerals, adds new economies to the art of mining by permitting the treatment of hitherto waste materials and also lean ore bodies.

The Discovery of Ore Bodies.—As though nature had foreseen and planned the age of industry, the rising tide of metal production was supported by the timely discovery of adequate ore bodies. The scattered and meager deposits of iron and copper and lead that supplied the colonists from mines in Pennsylvania, Massachusetts, New Jersey, and Vermont were infants compared with the vast mining operations of to-day; but they supplied the simple requirements and crude machines of that early day. As if by prearranged plan the large ore bodies came into view just as the revolutionizing improvements in metallurgy appeared, the railroad lines were being built, and the westward movement of population gained impetus. Michigan copper enters the scene in 1844. Almost simultaneously the iron ranges of Michigan and Minnesota, the source of to-day's steel, appear on the stage. The Marquette range is opened in 1854, the Menominee follows in 1872. Gogebic and Vermillion, in 1884, yield their production to an ever-growing industry and six years later, the Mesabi, largest of them all, began a career which soon carried it to the forefront of the iron industry and forms the backbone of the steel industry in Pittsburgh, Gary, Buffalo, and Cleveland.

In the meantime copper is making history. Michigan, the leader for nearly forty years, yields the leadership to Montana which state is soon surpassed by Arizona. In quick succession in the decade from 1870 to 1880, Butte, Mont., Clifton-Morenci, Bisbee, Jerome, Globe-Miami yield their hidden ores to the prospector. And, when mining technology reaches a point where it has solved the problem of treating lean ores, the "porphyries" most prolific of all, in Utah, Nevada and Arizona, offer their stores.

Truly, it is a fascinating and remarkable story, the emergence of scientific discoveries, inventions, technical progress, unparalleled transportation development, and discovery of the ore bodies. History and the rise of nations show no such parallel in the building of material civilization. Whether one wishes to credit the scientist, the inventor, the captains of industry, or the financiers for the coordination of the factors that have accomplished this result, one cannot conceive of such a consummation without the existence of large ore bodies and the prospectors and miners who brought them out.

The consequences of this large scale utilization of minerals profoundly affected the political and economic developments of the western world. The exploration of geologists and mining engineers tends to show more and more that the essential mineral products are far from evenly distributed over the land areas of the world. Western Europe and Eastern North America have more than a proportional share of those deposits that can be worked on a large scale, and it is the large-scale movements that mark the specialized character of the new industrialism.

The industrial revolution, which began in England, is the dominant characteristic of western civilization. From England it spread first to the western countries of the Continent, and developed there because of favorable conditions of mineral resources. The force of the movement faded out, however, toward the Slavic East and the Latin South; the mechanical industries of Italy are based on imported scrap. When the new industries became transplanted to the western shores of the Atlantic, the natural conditions which originally favored Great Britain were found to be reproduced on a larger scale. Thus in two main areas, separated by the North Atlantic, a family of industries based on mineral resources has risen to dominate the world. No other similar area in the world, so far as geology tends to show, seems to combine these essential features. A casual study of the industrial activity of nations discloses the fact that three districts—northern England, the Franco-German district bordering the Rhine Valley, and northeastern United States—embrace more than 90 per cent of the world's iron- and steel-making capacity. The basic elements requisite to the building up of an industry in these three centers are described by Leith as follows:

> A huge ore reserve of a suitable grade in a limited area, accessibility to population large enough and with sufficient industrial development to furnish demand, and control by people with organizing ability, driving power, technical skill, and capital to convert the ore into form adapted to demand. Once established, the inertia of invested capital helps to maintain production at a few places in spite of potentially favorable conditions in undeveloped regions.
>
> The dominant features of the United States production are the great reserves of high-grade iron ore around Lake Superior, the extensive use of the Great Lakes for cheap transportation of Lake Superior ore to the Lower Lakes, and the smelting of the ores principally in the region contiguous to the Lower Lakes, because of its

possession of abundant coking coal and because of its proximity to centers of consuming population.

The English iron and steel industry depends mainly on low-grade iron ore from four districts in England, of which the Cleveland district in northeastern England is the most important, followed by the Lincolnshire, Northamptonshire, and Cumberland-Lancashire districts. These districts have access to large supplies of coking coal and to the ocean. The low grade of the iron ores requires importation of high-grade ores, for mixture, from northern Sweden, northern Spain, and, to a less extent, from North Africa.

The great iron-ore supply of Continental Europe is centered in northeastern France, including Lorraine, and overlaps into Luxembourg. The coal beds which furnish the coke for the smelting of this lie mainly in Westphalia (in western Germany), with extensions into Belgium and northern France. . . . The valleys of the Rhine and its tributaries connect the coal and iron-ore fields. The industry is to be regarded as a single great unit, regardless of national boundaries. The low grade of the iron favors the use of considerable amounts of higher-grade ores in mixtures, and thus it is that ores are imported from northern Sweden and Spain." [3]

Iron and steel units of secondary or minor importance exist in Russia, Sweden, Spain, Poland, China, India, Australia, and Mexico, but these will be used to satisfy local demand only. None of these has the requisites in ore bodies, markets, or population to be a factor in world affairs.

These three centers, then, become the world's workshops. Once firmly established, the inertia of invested capital helps to maintain production in spite of potentially favorable conditions elsewhere. Out of these districts flow the finished goods—the machinery, structural products, railroad equipment, etc.—for domestic consumption or for export. Other types of industries, by reason of labor and market conditions, find it convenient to locate within or in proximity to the steel center. As examples, the chemicals, refractories, non-ferrous metal, tanning, and even the textile industries, as well as manufactures of a strictly local character, may be mentioned. The increasing density of population further enhances the market for manufactured products and reinforces the association of industries. Into these districts flow a large volume and wide variety of raw materials needed to supplement the domestic supply. The logical outcome of this geographic factor is the flow of accessory minerals from all corners of the globe to these three centers. As regards mineral raw materials, the nations of the world are virtually divided into two groups—those that supply raw materials and those that consume them in the manufacturing process.

In the succeeding chapters we shall discuss the distribution, movement, and industrial significance of the world's principal mineral commodities.

[3] Leith, C. K., The World Iron and Steel Situation and its Bearing on the French Occupation of the Ruhr, Foreign Affairs, Vol. 1, No. 4, June 15, 1923, pp. 137, 138.

CHAPTER II

THE ECONOMIC CHARACTERISTICS OF MINERALS AND MINERAL DEPOSITS

The mineral industry is world wide and the traffic in minerals knows no national boundaries. Ore deposits are geographically segregated. National sufficiency in mineral raw materials, if it ever existed, is unknown to-day. No nation is endowed with a complete array of economic minerals and many have a very limited number indeed. On the other hand, the industrial nations of the world, more specifically those bordering on the North Atlantic, need for their industrial processes all of the thirty or more minerals of commerce, and their ships go to all quarters of the globe to gather them.

Along with geographical segregation as a factor in fostering world movement of minerals is that of the properties of the minerals and metals themselves. No single mineral or limited group of minerals possesses all the properties necessary to satisfy the demands of a complex industrial civilization. Minerals and metals with unique and distinctive properties perform indispensable duties in industrial production, and these minerals frequently are far from the consuming industrial centers. A thorough understanding of the commercial significance of these factors requires a classification and description of the economic characteristics of minerals.

Mineral deposits may be classified in various ways. The geologist frequently does so on a basis of origin or mode of deposition. The mineralogist regards their methods of crystallization, chemical composition, physical qualities, and optical properties. The economist is not concerned primarily with these methods of classifying and describing them except insofar as they relate to those minerals which enter into the needs of industry, i.e., the minerals of economic importance. He cannot, however, ignore the classification of the geologist and the mineralogist altogether for, very frequently, they are keys to the economic characteristics.

Mineral Deposits Vary in Origin and in Geologic Surroundings.—The commercial value of an ore body is dependent not only upon its geographical location, but also upon the nature of the deposition and the geologic surroundings of the ore itself. Certain metallic ores occur in volcanic sublimates; others, like the titaniferous magnetites, are segregations or local concentrations in igneous rocks. The sands and gravels that yield chromite, tinstone, gold, and platinum are detrital in character; iron ores are frequently sedimentary rocks; some ore bodies are replacements brought about by solution of limestones; again others are deposited or precipitated from solutions. The nature of the ore formation may have a close relationship to its commercial value. Iron ores, for example, can originate in many ways, but only a few of these possible modes or origin have given rise to deposits of commercial value. The most important ore bodies from which the world's supply is drawn are of sedimentary origin. Replacement deposits make up the remainder.[1] A knowledge of these basic geologic facts is essential for the utmost possible economy in ore exploration.

The mode of origin of a mineral very frequently gives a clue to the geologic surroundings in which deposits are to be found. Petroleum furnishes an excellent example to a mineral whose occurrence and geologic surroundings enable the oil geologist to determine in a general way the rocks which are likely to be petroliferous or non-petroliferous. The conditions determining the presence of oil can be listed as follows:

1. Must be a supply of raw materials.
2. Conditions must be favorable for the preservation of the materials.
3. Partial distillation is necessary.
4. A reservoir is necessary.
5. A cover or seal is necessary.
6. Pressure is necessary.

The experienced oil geologist is able to exclude immediately large areas of the earth's crust as devoid of petroleum and concentrate attention to those formations where the conditions favoring oil are present.

The study of copper ore and of bauxite deposits reveal certain characteristics which aid the geologist in selecting probable ore-bearing areas. Bauxite, for example, is the result of vigorous leaching on alumina-bearing clays, hence the prospector searches the tropics for such deposits. He finds them in tropical South America, Africa, Dalmatia, India, and southern United States.

Ore Deposits Vary in Size, Quality, and Accessibility.—The term, ore deposit, viewed from a commercial standpoint, needs careful definition. In the ordinary sense ore is material which can be mined and marketed at a profit. The conditions which determine the potential

[1] Eckel, E. C., The Iron Ores, pp. 31–44, 1914.

profitableness of an ore body are found in the physical characteristics of the ore body, the state of technology of ore recovery, and the economic condition of the metal or mineral industry. Under physical conditions, we are concerned mainly with the richness of the ore, the size of the ore body, and its accessibility. The relation of an ore body to the technology of production is concerned with the extent to which advances in prospecting and mining methods change the conditions under which a metalliferous deposit can be profitably worked for the recovery of commercial metals or minerals. In its economic aspects, the value or existence of an ore body must be measured in terms of prices, competition from other mining districts, distance from markets, tariffs, etc. With all these variable factors concerned, the question may well be asked, "What is an ore body?" This question can be approached by consideration of a deposit of metalliferous rock of varying degree of metal content as a potential ore body. Under what conditions does this deposit constitute an ore body and when does it fail to meet this characteristic? Obviously, the classification of such as an ore body is a resultant of all the total existing relations of costs of mining and market prices. If selling prices exceed total costs, the deposit may be classed as an ore body. However, any one or all of the variable factors which make up this relationship may change. Prices may go up or down. In the one case it may be profitable to treat leaner portions of the ore body, in the other, a working of the ores near the margin may have to stop. Thus the size of an ore body is not a fixed and definite quantity but is varied by changes in price. Or improvements in mining technology may alter conditions. Increased effectiveness of ore treatment may bring into the range of commercial ore materials that hitherto were regarded as waste or "sub-ore" or "non-ore." This means that with changing conditions as to cost and price, the extent of an ore body likewise changes, there being a continual shift back and forth across the borderline between waste and "sub-ore." The manganese situation in the United States may be used as an excellent example of this principle.

For many years before the European War, the United States produced less than 1 per cent of its high-grade manganese consumption, supplies of this character being imported from Russia, India, Brazil, and elsewhere, both as ore and as high-grade alloy. Domestic deposits were known to exist, but under natural conditions of unrestricted flow and free interchange, they could not compete with foreign sources. In short, with the possible exception of a comparatively few thousand tons, the United States had no high-grade domestic manganese ores. With the advent of the war, conditions became increasingly abnormal. Prices soared and standards were lowered, with the result that in the year 1918 the United States produced 305,000 tons of ferrograde ore, furnishing 23.6 per cent of the manganese used in high-grade alloys. In addition to this, 86 per cent of the manganese used in low-grade alloys came from domestic sources. Thus, under war conditions, the United States was proved to possess considerable domestic resources of high-grade as well as low-grade ores. This clearly demonstrates the necessity of determining the conditions under which ore is produced in order to estimate the extent of the reserves.

Size, likewise, is an important consideration in determining the commercial value of an ore body. This, too, depends upon the conditions prevalent in the mining industry. The small bog iron ore deposits of the Atlantic States were ore bodies in the colonial period when the production of iron was small, the methods of mining and reduction were crude, and no large ore bodies were in sight. With the discovery of the immense ore bodies of the Superior district coupled with the advent of steam-shovel mining, elaborate transportation systems, and a demand for iron and steel in quantities of thousands of tons, the scattered deposits of bog iron ore ceased to exist commercially. This is, to be sure, an extreme example, but the instance is used to illustrate the point that, for profitable exploitation, a deposit must contain sufficient ore to warrant the investment of large capital expenditures in costly and elaborate mining equipment.

Domestic potash deposits afford another illustration of a physical reserve depending upon price conditions and size in order to be classified as ore. The cessation of German potash imports during the war forced the exploitation of domestic resources with the result that potash was recovered from the brine deposits of Searles Lake, California, the salt marshes of Nebraska, the Salduro Marsh, Utah, and elsewhere. The return of Germany into the world's potash markets immediately caused a closing of operations in the small scattered deposits of Nebraska, whereas the American Chemical and Potash Corporation, operating in Searles Lake, continued partly because of the size of the reserve from which it obtains its product.

Quality of ore is another factor by which ore is measured. Quality is here defined as the percentage of metal in the ore and does not consider the matter of impurities. Again the Lake ores may be used as an illustration. The iron-bearing rocks of this region run into billions of tons. The iron content ranges from a few per cent to rich deposits more than 60 per cent ore. Where is the line between ore and sub-ore? Under present market conditions and mining practice the industry ships ore only of 40 to 60 per cent. As long as these conditions remain unchanged, the reserve of ore can be measured with a reasonable degree of accuracy and the date of exhaustion almost predicted. However, much can occur in the intervening years. A rise in the price of iron, further economies in mining, an entirely new technique of ore reduction may bring into the zone of commercial ore many low-grade deposits of no present value. On the other hand the importation of high-grade foreign ores may be accomplished at costs that make the working of these mineralized rocks impossible. Ore of commercial quality, just as the commercial size of deposit, is dependent upon a condition made up of the several elements of price, cost of mining, technology of recovery and reduction, competition, etc. Estimates of ore reserves based on quality can be tentative only.

Accessibility as a factor is concerned mainly with ease of recovery and distance from market. The geologic surroundings of the ore, whether it be deep-seated or surface, and its location with reference to lines of transportation and distance from the blast furnaces or smelters cannot be overlooked. Thus the ore that is very desirable from the standpoint of chemical composition and physical condition may be located as to be practically inaccessible. On the other hand, a poor ore may be so conveniently located that it may be concentrated at a profit. The porphyry copper ores of western United States are able to compete with the Katanga deposits in the heart of Africa mainly because of the transportation factor, although the former are much leaner in copper content. Likewise, the iron ores of the Birmingham district, because of underground mining methods, cannot be exploited in the same manner or rate as the open pit mining of Minnesota. It has been estimated that the Birmingham ores will last 300 years or more at the present rate of production, a rate governed largely by the geologic conditions surrounding the deposit. Obviously the present commercial value of the two ore bodies is not comparable. The bituminous coal mining industry of the United States affords numerous illustrations of deposits of varying availability and accessibility.

By taking into account mining costs, such as the inherent difficulty of mining thin seams, or of mining at great depth, together with the metallurgical value of the product, Roessler[2] uses the following system of classifying the Lorraine iron ores.

"Known" ore is developed material that is or can be profitably mined now.

"Probable" ore is material that may probably be mined hereafter, probability being based on present standards in mining and metallurgy and on geologic indications as to continuity of the deposit.

"Possible" ore includes ore of present commercial grade which lies

[2] Bulletin 703, U. S. Geological Survey, p. 12.

so deep that now it is not available but which a slight improvement in mining methods or an increase in price would render available; ore which is of lower grade than that now used in a not very distant future; ore which is used chiefly as flux; and ore which chemically is not fit for use in present metallurgical practice but that may be used in the future, such as titaniferous ore or ore containing a large quantity of silica.

This classification has the merit of avoiding a hard and fast tonnage estimate and allowing for the various economic factors and conditions that alter the extent of a commercial body.

Ores Vary in Physical and Chemical Properties.—The value of an ore as a source of metal or mineral is conditioned by its physical and chemical properties. Hardness, water content, physical structure, and content of foreign matter must all be given consideration in determining the availability of an ore for reduction and treatment.

Hardness of ore affects mining costs and presents problems in furnace operation. The domestic iron ores, for example, exhibit the widest variation, ranging from soft clay-like or earthy matter to hard, compact masses. Both extremes tend to give trouble in the blast furnace. The soft ores tend to choke up the furnace, a difficulty which is overcome to some extent by judicious mixing with hard ores, while the very hard and dense ores which enter the furnace in comparatively large lumps are difficult to reduce and require an excessive amount of fuel.

Water or moisture is a factor in the commercial value of an ore mainly because it adds to the weight of the ore to be handled and transported, and uses up fuel to drive out the moisture.

Impurities in ore are mainly of a chemical nature and affect in various ways the commercial value of the ore. In this connection an ore may be considered a metalliferous mineral associated with other minerals non-metalliferous in character. These latter are called gangue and add weight only. Their separation and removal is accomplished usually near the mines. Another group of impurities are those which add to the cost of reduction of the ore in the blast furnace or smelter. To this class usually belong these minerals so intimately mixed with the valuable ore that they cannot be separated by the ordinary processes of concentration and beneficiation. These are removed in the slag. Certain impurities interfere with the processes of reduction and, if present in appreciable quantities, militate against the use of the ore. This is true of the titanium-bearing iron ores of New York State. A high silica content in bauxite, the ore of aluminum, represents a similar case.

When these impurities are of a nature that they can be removed though at an increased cost of furnace operation, the ore in question may still be so situated as to be desirable commercially. However, if the impurities in the ore find their way into the finished metal, the problem may be more serious. For example, a high phosphorus content in an iron ore definitely prevents its use in the manufacture of Bessemer steel.

The chemical composition of coal is so important that it virtually divides this substance into several groups. Thus, we have gas-making coal, coking coal, by-product coal, steaming coal, etc., the division being governed by such elements as sulphur content, volatile content, etc.

Minerals are Wasting Assets.—Mineral resources are not self-replacing. In this respect they fall into a class apart from agricultural land or forest land resources upon which a crop can be periodically harvested. What significance is attached to this characteristic? The answer to this question depends upon any one of various viewpoints taken. For clarity of discussion, these may be listed and the problems presented to each may then be discussed.

1. The corporation engaged in mining or using the product of the mine.
2. The nation.
3. World viewpoint.

It is essential to recognize that the value of a mineral deposit to a private individual or corporation comprises mainly two elements: an intrinsic element based upon the qualities of the material itself, and an extrinsic element based upon its availability and the nature of the demands for it. The former element is concerned with the factor of depletion. A corporation desires to engage in the business of mining either to sell its product in the open market or to supply its own furnaces or smelters. What elements does it take into account in acquiring a mineral property? Obviously, the size of the deposit. Unless this is known, the expenditure of capital on mining equipment is an unwarranted hazard. Secondly, the rate at which the ore can be recovered from the mine. This is governed by two factors, viz., the physical surroundings of the ore body itself, and the condition of the market. The market condition is of prior importance. A forecast must be made of the probable market price of the ore based on all the information possible, such as past prices, trend of the industry, future prospects, etc. As a matter of safety, discounts on the market price must be made to cover such contingencies as a drop in the price of ore, labor troubles, or accidents to the mine. The determination of market conditions can then be followed by a study of cost of production—a complex problem in the mining industry. The ore body must be prospected by core drilling or other methods to determine its extent, quality, and tonnage content. It must be large enough to justify an expenditure for the installation of modern mining and ore transportation equipment. Not only must the returns from the mine be large enough to pay interest charges in this investment but also to write off the capital investment by the time the mine is exhausted. The cost of the ore itself must be calculated. This involves several factors which can be illustrated by assuming a specific problem. Consider, for example, a deposit of 1,000,000 tons of ore. This would be valued at one million dollars if all the ore could be removed immediately at a profit of one dollar per ton. It is quite likely, however, that not all of the ore is of proven quality, hence a discount would have to be made for "probable" ore, that is, ore whose quality or extent is not definitely determined. Secondly, a discount must be applied to the ore that cannot be removed immediately. In other words, the unmined ore must be discounted at the prevailing rate of interest times the number of years elapsed. For example, if physical conditions permit the removal of 100,000 tons annually, with an immediate value of one dollar per ton, the next 100,000 tons must be discounted, say 8 per cent, or the interest rate for one year, and each succeeding 100,000 tons be discounted 8 per cent times the number of years that elapse after the investment is to be made. This must be further qualified by conditions of the market. The capacity of the market to absorb the output may be less than the physical capacity of the mine, as a consequence of which a further discount must be applied. If a property runs beyond thirty years, the value of excess ore is practically zero unless the market price will continue to rise. This method of valuation of a mining property is known as the "ad valorem" method. The actual sale value is usually below the value arrived at by the ad valorem method, a discount known as the "margin of safety."

Generally speaking, once a mine is opened, economical operation favors as rapid exploitation as possible.[3]

As mining and metallurgical companies evolve into larger units, more and more it becomes necessary for them to take a long time point of view of problems thus coinciding with a national point of view.

From the national point of view the wasting character of mineral assets presents a problem of a different nature. Whereas an individual mining company can purchase other properties when their existing ore reaches exhaustion, the nation must be concerned with the problem of insuring an adequate supply of minerals for an indefinite future. This touches directly upon the controversial question of conservation of mineral resources, a question which is controversial largely because its meaning is little understood. The accelerating rate of mineral con-

[3] Hoover, Herbert, Principles of Mining, 1909.

sumption in the past few decades cannot but raise the question of ultimate supply and the ability of a nation to maintain a high rate of output for an indefinite time. An initial step is obviously a careful taking of stock. Such an undertaking can arrive at approximate results only, since the concealed nature of mineral deposits and the improving technology of mining operations means that new discoveries will continue to disclose hidden supplies and that progress in mining methods and ore treatment will bring into the zone of commercial ore much material that is now considered waste. Nevertheless, the limits of mineral resources are small compared with the expected life of a nation or of civilization so that the fundamental need of stock taking and prudent utilization is not changed. A situation of more immediate concern exists where a mineral resource, however abundant its total world supply may be, is not found within the boundaries of a nation, particularly industrialized nations like the United States and the countries of western Europe. The problem in this case is not one of conservation, but of making international arrangements to safeguard, as far as possible, the uninterrupted flow of the minerals to the consuming nation. For the United States this is particularly true of tin, nickel, platinum, antimony, vanadium, zirconium, mica, monazite, manganese, graphite, asbestos, ball clay and kaolin, chalk, cobalt, and some other minor products.

Minerals are Localized and Restricted in Their Distribution and Are Frequently Hidden from View.—Nature has not taken into account the political boundaries of nations in its distribution of mineral supplies. Some kinds of minerals are so widely distributed that nearly all countries have adequate supplies within their own boundaries or near at hand. Other minerals are so distributed that some parts of the world have a surplus and others a deficiency. No country is entirely self-sufficing in regard to either supplies or markets for all mineral commodities so that international exchange of minerals cannot be avoided if all nations are to be supplied with needed materials. The necessary international movement of minerals may be aided or hindered by bonuses, preferential duties, tariffs, and embargoes, but in the long run, the main international channels of mineral movement determined by nature cannot be altered by legislative enactment. Economy of mineral shipping and handling dictates the necessity of the reduction of bulk by concentrating and refining many needed minerals at the source of supply rather than in the centers of consumption. The copper-smelting industries of the western states and of South America or the tin-smelting plant at Singapore are examples of minerals whose nature and geographic location require smelting away from the world markets.

Minerals and Metals Vary in Their Properties and Usefulness.—The basis of the demand for the large variety of minerals and metals used in the manufacturing industry lies in the differing physical properties of the metals themselves. It has been previously stated, and is repeated here, that the industrial process has become so complex that the raw materials which it uses must have a wide variety of properties in order to satisfy the exacting demand. No single mineral or metal can perform these services or meet these demands. It is true that some of the metals exhibit a wide range of uses. Thus iron and its chief alloy steel can be varied in hardness, toughness, resiliency, resistance to corrosion or abrasion, etc., by varying the form and quantity of carbon, or by adding small quantities of metallic alloys. In spite of the ubiquitousness of this metal there still remain industrial processes which need the special properties of the other metals for their proper performance. What each metal does and the part it plays will be reserved for discussion in later chapters. For the present we shall limit the discussion to *the functional relationship of the minerals in industry.*

The Functional Relationship of Minerals in Industry.—The many manifestations of human comfort and welfare—the contributions of the machine age—are due in no small degree to the effective cooperation of the minerals and metals as well as the diversity of their serviceable properties. The metals and minerals not only give us the machine age, they also determine the place and the time where this industrial civilization shall attain its most complete fruition. The point of beginning the discussion of this subject is with coal. This fuel has played a major role in the advance of civilization and is one of the most valuable commodities known to man. It not only keeps him warm and cooks his food, but supplies him with light, with water, and oftentimes with air itself. It is a source of power; it is used in making almost every article in his house and in making the house itself. "It transports him by train or boat; it prints his books and papers, and prepares the wires to carry his thoughts. Coal brings to man's door the products of the whole world. Its distillation adds nearly a thousand by-products, from the vaseline that soothes his pains to the tar that smooths the roads he travels. Without coal life would drop back into the laborious poverty of primitive times. Oil and gas may for a few years relieve in slight measure our need of coal; water power will permanently relieve some of the demand on our coal deposits; but to-day and for many centuries our use of coal will be the simplest measure of our material civilization.

The industrial function of coal as a teammate of other minerals and metals is equally important and significant. Coal first makes metals available for man's use by reducing the refractory metalliferous ores of nature and releasing the metal. Before the introduction of coal for this use, man was limited to the extraction of a few pounds of iron, or copper, or lead, by means of charcoal from quickly exhausted forests. The advent of coal—and coke—marked the dawn of the metal day. Metal became cheaper and more abundant. The way was opened for steam power, steel railroads, and steel ships—the necessary handmaidens of industrialism. This is not all. Coal as the releaser of metals became the basis of national industrial and political power. England, Germany, and the United States rise to world leadership upon rich deposits of coal.

The release of the metals from their native ores placed another duty upon coal—the duty of motivating machinery. The wheels of industry and transportation are turned by the power of the steam engine. Step by step, from James Watt to the present day, we see the burden of human labor shifted to coal, and man, released from arduous physical labor, immediately finds larger and larger loads for his inanimate substitute. To-day each workman directs mechanical power equivalent to many scores of human workers. This is but a brief mention of the fundamental services of coal. Its place in home heating, in the chemical industries, and other special services, less directly associated with the operation of the industrial organization, can only be mentioned.

The work of coal cannot, however, go on without the cooperation of the metals, and foremost in importance is iron. Without coal, iron, in large amounts, could not be available; conversely, without iron, the energy of coal could not be harnessed and directed into useful channels. The two are almost inseparable as Siamese twins. Fortunately, iron is abundant, cheaply reduced, easily worked, and possesses physical properties which make it peculiarly available as an ally of coal. Iron and its chief alloy, steel, can be given a wide variety of properties through appropriate methods of heat treatment and working. This advantage, possessed by no other metal to the same degree as iron, manifests itself everywhere in the industrial plant. Iron can be made resistant to abrasion as needed in the jaws of an excavating machine, or to impact as in the nickel steel of a battleship. Alloyed with minor quantities of other metals it exhibits rustlessness, special cutting properties, unusual toughness or hardness, ability to withstand torsional strains or shocks. We are in reality dealing not with one metal but with a group of closely related alloys of a metal. Iron, and iron alone, lends itself to such a long list of valuable uses.

The important place of iron and coal in industry is reflected in their output as compared with other metals. Exclusive of stone, gravel, sand, etc., coal represents 95 per cent of all mineral tonnages, and iron represents 90 per cent of the nation's metallic output.

These minerals may be considered basic to industry and industrial location. The presence of coal and iron fix the location of industrialized areas. Practically all other minerals flow into these centers. Whether the coal will move to the iron, the iron to the coal, or both move to a point midway is determined by factors within the general coal-iron area itself, such as labor, markets, and transportation facilities.

The discussion of iron would be incomplete without special mention of the industrial significance of one of its unique properties—magnetism. Iron alone, of the various metals, is magnetic to an appreciable extent. Cobalt and nickel also possess this property to some degree, but their scarcity in nature and high cost militate against their wide usage. The magnetic property of iron is fundamental to and makes possible the construction of electrical machinery. The motor and the generator, around which the modern method of electrical power production is built, can harness electricity only because the cores of the rotor are built up of laminations of the quickly magnetized and demagnetized soft iron. Equally dependent upon this property are the modern instruments of communication, the telegraph, the telephone, and the radio.

To enumerate the other electrical devices that employ the principle of magnetism would be like cataloguing the products of an electrical manufacturing company. One need but mention the electrical measuring instruments, those delicate meters of precision which are present in the most exacting research laboratories as well as the large city power plant. Take away from iron the property of magnetism and the effect upon our industrial order makes a diversion for the imagination on some idle afternoon.

The interrelation or interdependence of minerals becomes more and more involved with each onward step. The discussion of electrical machinery introduces copper into the modern age. It is the third member of the group underlying the electrical component of industrialism. If copper has a multitude of industrial applications its really unique contribution is that it is the most effective carrier of electrical energy. Like iron, it is comparatively cheap and abundant, and no other metal, with the exception of the more costly silver, approaches it in electrical conductivity. Its nearest competitor is aluminum. This metal now looms up as a possible rival of copper in the transmission of electricity over high potential long-distance transmission lines, but in the construction of motors and generators, telephones, electrical measuring instruments, etc., copper is likely to hold the field.

These three metals, coal, the reducer and energizer, iron, the harnesser, and copper, the conductor of electrical energy, by combining and coordinating their peculiar properties, lay the foundations of human control of the forces of nature in a truly remarkable way.

At the risk of being arbitrary, we will divide minerals into two industrial groups, the basic minerals, the three mentioned above, and the contributory minerals. The building of machinery—cotton looms, hosiery knitters, farm harvester, automobiles, or the manufacture of electrical power—is carried to a far greater degree of technical nicety, in fact may be even impossible without the assistance directly and indirectly, in small quantities or large, in a few services or in many, of a dozen or more other metals—the contributory group. The uses of metals alloyed with steel have been mentioned. When such metals as nickel, manganese, chromium, etc., are added to steel they impart qualities that improve the services rendered by the steel. This is one function of the contributory metals. Other functions may be mentioned. Platinum, as a necessary catalyst in sulphuric acid making acts as a key which unlocks a cheap process of chemical synthesis; antimony is essential to the production of clear printing type metal; mercury is a key metal in precise scientific instruments; the nonmetallic minerals such as sulphur, arsenic, silicon, etc., play equally important roles. Later chapters will deal with these metals in detail.

The foregoing brief survey of the characteristics of minerals and mineral deposits, the properties of metals, and their functions in industry serve but to emphasize the essential unity of the various aspects of the mineral industry. Intelligent formulation of policies dealing with the administration of mineral resources, whether it be taxation, valuation, tariff making, conservational measures, or regulatory legislation must take into account and view the mineral industry in all of its phases.

CHAPTER III

THE IMPORTANCE AND PLACE OF POWER

FIRE and mechanical power are two important cornerstones in human affairs. Primitive man early discovered and used fire to warm his crude shelter and to protect himself against his animal enemies. Man's conquest and preservation of fire enabled him to adopt a sedentary life, in contradistinction to his feral neighbors, and aggregate into groups having the germs of state. When he learned to produce fire at will, man became free to migrate and form colonies and groups in different zones. From the simple beginnings of the camp fire have grown a large number of the arts that have supplied man's primary wants, such as cooking, offense, and defense.

The development of mechanical energy is closely associated with the use of fire for by means of the latter man learned to release and harness mechanical energy out of which developed the secondary arts of agriculture, timbering, boat building, metallurgy, ceramics, etc.

Other forms of energy, besides that released by fire, were also used to furnish power. Man first depended to a large extent upon his own muscles to do his work. He next domesticated the animals—horses, oxen and mules—to lighten his own work. He harnessed falling water and, even before the modern time, derived energy from this source. To what extent wind power, both on land and sea, was used cannot be known, but certainly it has occupied an important place. Prior to the use of steam in industry and transportation, the vast extent and naval power of the British Empire was built on sailing vessels. "Sea Power," to use Mahan's phrase, then resolved itself into capacity for utilizing wind power. "It is largely the truth that our Empire was created, preserved, and sustained by our skilful use of the wind." [1] The use of wind has declined; while the sailing vessel was superior to the early side-wheel driven steamer, the screw and the compound engine together decided the issue in favor of coal. On land the windmill is confined mainly to the work of pumping water on farms and ranches. The use of wind as a source of power, while very limited,[2] is by no means to be

[1] Carlill, J., Wind Power, Ann. Rept. of Smithsonian Inst., 1920, p. 154.

[2] Tryon estimates that wind power supplied 0.1 per cent of the total energy consumption of the United States, Coal in 1927, U. S. Bureau of Mines, p. 405.

dismissed altogether. Improved wind motors with greater efficiency of utilization, used in conjunction with means of storing power during calms, may yet be revived, as a supplementary source of power. And on the sea a combination of Diesel engines and sails offers possibilities of economy that deserve consideration.

The invention of steam engines opened the way toward converting heat energy into mechanical energy. Wood was burned to raise steam as well as to heat houses. As charcoal it also occupied an important place in smelting iron ores. Although inferior to coal, which rapidly replaced it, wood is still a minor source of heat and power.[3] With wood becoming scarcer and more valuable this use will probably decline.

The enormous release of energy annually, as shown by the prodigious use of coal and its hydrocarbon allies, oil and gas, has raised the question of ultimate fuel exhaustion, and has stimulated man to search nature for other sources of energy.

Peat is used to some extent as a fuel in Europe and has been the subject of experimentation in the United States.[4]

The almost limitless power of the waves and tides has attracted attention and repeated attempts to harness this power have been made. While occasionally sites are available along the seacoast where conditions permit the practical harnessing of tides,[5] and will no doubt be of local value, these instances are too rare to make an appreciable contribution to the total power needs. In regard to wave power, the world still awaits the design of a suitable and practicable motor.

Another method of obtaining energy from the sea is indicated by the experiments of Claude and Boucherot, in France, upon the utilization of the small but very constant temperature differences that exist between the sun-heated surface of the tropical oceans and their deeper layers. These French investigators "were able to demonstrate that a small Laval turbine designed to be driven by steam within pressure limits ranging from 20 to 0.2 of an atmosphere, can advantageously be driven by water vapor with tensions between only 0.04 and 0.01 of an atmosphere, corresponding to temperature-differences between 25° and 8° C. only. According to their calculations and experiments, a net output of 54,000 kilogram-meters could be obtained from each cubic meter of water between 28° and 5° C., if there be subtracted the energy that is necessary for pumping the cold and air-free water from the depth of the ocean to its surface. An installation of this kind having

[3] 5.5 per cent of the country's energy consumption in 1927, op. cit., p. 505.

[4] Odell, W. W., and Hood, O. P., Possibilities of the Commercial Utilization of Peat, Bulletin 253, U. S. Bureau of Mines, 1926.

[5] Passamaquoddy Bay on the coast of Maine, for example.

a capacity that effects the displacement of 1,000 cubic meters of cold water every second, would be able to produce 400,290 kilowatts of electrical energy, this efficiency being about thirty or thirty-five times as great as that of a low- and high-tide plant of the same dimensions. In their provisional installation at Ougree-Marihaye, Claude and Boucherot recently demonstrated before a meeting of engineers that a turbine could be run by utilizing the slight temperature-differences of the water of the Meuse, ranging only from 28° to 8° C., and that it could drive a dynamo with a capacity of 59 kilowatts. The calculation by Boucherot of the necessary costs of installation seem undeniably to indicate that the practical realization of this idea lies very probably within the limits to technical possibilities."[6]

The direct use of solar energy has been the subject of experimentation and methods of capturing the sun's heat have been devised. The value of this source is circumscribed by limitations which seriously interfere with its practical application. One method of concentrating the sun's rays upon boilers to raise steam carries with it the objections that it cannot be used at night, that, for most effective use, it must be installed in cloudless regions, the deserts, and the equipment needed is too costly to result in economical power production.

The utilization of the sun's rays by means of the photosynthesis of starches and celluloses has been studied. Aside from the doubtful mechanical devices mentioned above, photosynthesis is the only means we have of capturing and utilizing solar energy. This method is so very inefficient and subject to such great uncertainties that it is exceedingly doubtful whether it can be depended upon to maintain our energy requirements. Moreover, the use of photosynthesis as a source of energy would seriously encroach upon the world's acreage needed for food supply. In a study of "Photosynthesis and the Possible Use of Solar Energy,"[7] H. A. Spoehr states the elemental proposition in the question of capturing and utilizing the sun's energy by means of photosynthesis. Using 15 calories per square centimeter per minute as the intensity of solar radiation reaching the earth, Spoehr calculates that the heat received in 90 days' insolation on an acre is the equivalent of 1476 tons of coal. As a matter of comparison the heat stored up by a 50-bushel crop of wheat per acre contains the equivalent of 0.623 ton of coal. "This last figure of about two-thirds of a ton of coal is to be compared to the 1476 tons, representing the total solar radiation during a period of 90 days, approximately a grow-

[6] Jaeger, F. M., The Present and Future State of Our Natural Resources, Science, n. s., Vol. LXIX, No. 1791, April 26, 1929, p. 443.

[7] Spoehr, H. A., op. cit., p. 182.

ing season." Boyd [8] calculates the possibility of making motor fuel from corn starch, but so inefficient a use of solar energy would require an area equal to four times that of Ohio.

One other plant material, cellulose, has received consideration as a possible source of liquid fuel.

"Much of the speculation as to the use of cellulose for conversion into alcohol is based upon the utilization of waste material in the forests and at the mill. Of the 26 billion cubic feet of wood cut annually, the major portion represents accumulated virgin timber, so that this source cannot be considered as a permanent one. To what extent and how soon the depletion of virgin forests will be met by an intensive forestry program is a practical question that seems difficult to answer." [9]

It seems highly questionable whether the use of the products of photosynthesis offers much promise as a source of industrial energy. The scientist must find a way to increase substantially on nature's efficiency in storing up the sun's energy in cellulose and starches, if it is to be available at all.

The recent researches in the physics of the atom has raised man's hope that he will eventually be able to harness its enormous energy—a hope once shared by some of the scientists themselves. However, as the nature of the atoms becomes better understood and the probable mode of atom building and disintegration is explained, this remote hope fades into an improbability.

The energy available to him [man] through the disintegration of radioactive, or any other, atoms may perhaps be sufficient to keep the corner peanut and pop-corn man going on a few street corners in our larger towns for a long time to come but that is all.[10]

The energy available through the building up of atoms from hydrogen would be enormous if it could be made to take place on earth, but apparently this process can go on only in interstellar space.

While a study of the various sources of energy is extremely interesting and fascinating to the chemist and the physicist, the student of industry must confine his attention to those sources of energy which comprise the world's work—coal, oil, natural gas, and water power. Wind power, firewood, and animal power may be mentioned as minor auxiliary

[8] Boyd, Motor Fuel from Vegetation, Journal of Industrial and Engineering Chemistry, 13 (1922), 836.

[9] Spoehr, H. A., op. cit., p. 183.

[10] Millikan, R. A., Available Energy, Industrial and Engineering Chemistry, Vol. 20, No. 10, Oct., 1928, pp. 1117–21.

sources. A study of power consumption assigns a distribution of energy supply (in 1928) as follows:

TABLE I *

RELATIVE IMPORTANCE OF ENERGY SOURCES

	Per Cent
Coal, bituminous and anthracite	67.4
Lignite	5.4
Oil and natural gas	18.2
Water power	9.0

* U. S. Bureau of Mines, 1929.

The history of energy utilization reveals a remarkable evolution in the relative importance and changing functions of these forms of energy. Before modern fuel technology attained such large significance, each of the energy groups occupied a position almost to the complete exclusion of the others. Anthracite monopolized the field of domestic heating; bituminous coal dominated in transportation, manufacturing and smelting; gas was used mainly for lighting and cooking; water power became associated with the infant, but rapidly growing, electric light and power industry.

These more or less sharply defined functions of each of the energy groups are tending to disappear. Fuel technology has widened the field of service for each of these energy sources so that all of them are competing more and more sharply with each other. The product of petroleum, e.g., fuel oil, encroaches upon the use of coal in domestic heating, ocean and rail transportation, gas making, central station fuel, and industrial heating. Coal, on the other hand, in a pulverized form, bids fair to assume the properties and perform the services of a liquid fuel. Water power experiences a rapid rise with the expansion of the electrical industry only to find its further expansion made more difficult by the increasing efficiency and lower operating costs of steam-electric plants.

The outcome of this present competitive position of the energy sources is a partial geographic segregation of the consumption of the different types of fuels. Coal is practically excluded from California and is of minor importance in Texas, Oklahoma, and the bunker trade of the Pacific and Gulf ports. Coal dominates in the industrial northeastern United States and New England where the long haul of fuel oil precludes competition on a price basis. The two fuels engage in keen competition in the Interior and Lake States. In the industrial nations of

Europe, the presence of large quantities of coal and cheap lignite has prevented fuel oil from obtaining a foothold except for bunkering and naval use.

A by-product of this competition among the fuels is a remarkable increase in the effective heat and power extracted from the fuels with especially notable achievements in the use of coal.

WATER POWER

A discussion of the energy sources and material is not complete without reference to the present status and future probable use of water power. Important as a source of mechanical hydraulic energy before the advent of steam, this use has become obsolete and its principal value lies in its contribution to the energy supply in the form of electrical energy.

The development of water power in this country has extended consistently and now supplies a substantial portion of the electrical output of central stations. Its relative importance in this field is most accurately portrayed by a comparison of kilowatt-hours output by fuels and by water power. The situation in 1929 was as follows:

TABLE II *

KILOWATT HOUR OUTPUT OF CENTRAL STATIONS

	Kilowatt Hours	Per Cent
Total	97,293,683,000	100
Fuel power	62,684,017,000	64.5
Water power	34,609,666,000	35.5

* U. S. Geological Survey, report of Feb. 17, 1930.

The above represents the relationship of water power in the field of central stations only. When the total energy requirements of the United States are taken into consideration, the contribution of water power is calculated at 6.3 per cent.

The theoretical potential contribution of water power to the power supply has been estimated by the U. S. Geological Survey as between 50 and 60 million horsepower [11] and, with the installation of storage

[11] World Atlas of Commercial Geology, 1921, Part II, Water Power of the World, p. 13.

facilities, a figure somewhat above that. There are, however, certain limitations that must be considered which effect a substantial reduction from the theoretical hydro-power that may be utilized. Previous to the Federal Power Act of 1920, the legislation governing the use of water power was unsatisfactory and discouraging to investors or entrepreneurs who might wish to develop a desirable site. This condition has been so improved by the Act of 1920 that water-power development has received a great impetus as shown by the number of applications for permits and licenses filed with the Federal Power Commission.

A second limitation is the unfavorable geographic distribution of potential water-power sites. At least 70 per cent of the potential water power of the United States is located in the Mountain and Pacific States where the market for electrical energy falls far short of what the water falls could supply. Even though the energy of the falling water be converted into electrical energy, the technical and economic limitations of power transmission prevent its transportation to the populated centers farther east. Nor do the industrial conditions and natural resources of the Western States offer promise of a development extensive enough to require the power potentially available.

Finally, water power must be considered as one of a group of competing sources of power. While there are water power sites so favorably located and topographically formed that they can be developed to furnish power at a cost with which fuels cannot compete, this is more likely to be the exception than the rule. The progress in fuel economy is making such strides that the costs of steam-generated power is going down and will continue to do so for some time. In water power development the opposite tendency is likely to be the case. The lowest water power sites are likely to be developed first. As these are taken up, it is necessary to seek higher cost and more remotely located water powers, until a point is reached where steam can supply power cheaper than water. A study of the applications before the Federal Power Commission indicates that the maximum of profitable development may not exceed 25 million horsepower for some time to come. The approval of the Federal Power Act in 1920 was followed by a flood of applications for permits and licenses. The applications in active status at the end of each fiscal year, together with the percentage of increase are shown in table on page 31.

The sharp decline in the rate of increase after the first year may be an indication that, for the present, nearly all the sites that can be developed at a profit have been covered by applications.

A study of the water power resources of the United States and Canada show that considerable water powers of economic value are located

Year	Net Installed Hp.	Percentage of Increase over Previous Year
1921	15,024,000	..
1922	19,995,000	33
1923	21,415,000	7
1924	21,695,000	1
1925	24,119,000	11
1926	24,755,000	3
1927	24,981,234	1
1928	24,639,995	..
1929	23,381,611	−4

in the St. Lawrence Valley, Quebec, Niagara Falls, the Southern Appalachians, and portions of the Far Western States.[12]

[12] For a detailed discussion of the water-power situation consult the author's work on "Economics of Water Power Development," 1928.

CHAPTER IV

COAL RESOURCES OF THE UNITED STATES

THE need for coal in everything that man does, building, transporting, making tools, and goods, in the production of power, light and heat—has been told over and over again by writers on every one of those many occasions when a crisis in the coal industry compels the average man to think about, berate, or demand an investigation of the coal industry. The literature of coal is many times as extensive as a " five-foot shelf " and vies with love and war as a theme for the employment of printer's ink.

Of the various forms of energy coal is the most abundantly used. When man transferred labor and toil from his own muscles to mechanical motors, he found in coal his ready and faithful ally. The rise of petroleum and water power in the last few decades has profoundly affected the coal industry in many respects but these two forms of energy, singly or combined, have not succeeded in displacing coal from its position of first importance in the supply of power.

The Industrial Function of Coal.—The role of coal in human society is many sided. It extracts metals from the earth, furnishes power and heat, and is the raw material for a lengthening list of chemical products useful in the home, in medicine, in manufacturing and in agriculture. In supplying the basic need of industry—the metals—coal is the key which serves to recover these metals from their state in nature. The primitive industrialists, it is true, used charcoal to wrest from nature the few pounds of iron that they used. But charcoal became scarce and the demand for iron increased. Man, in his attempt to escape from the tyranny of uncontrolled natural forces, through mastery and subjugation, needed both coal and iron in abundant quantities. Coal became the premier agent in the smelting industry. To a certain degree coal may even become a substitute for metals. When the richer ores are exhausted, and recourse to leaner metalliferous ores becomes necessary, a larger quantity of coal used in smelting will offset the lower metallic content and ores too lean to work now will in the future give up their metal. The relation of coal to the metals, the former acting as the key by which the latter are released, while these in turn act as the harness by which the energy of coal is controlled and directed, is the basis of industrial progress.

Entirely apart from its function in the recovery and production of metals is the function of coal in the production of power. This finds expression in a multitude of ways. In addition to the very obvious role of coal in raising steam under boilers in locomotives, ships, central stations, threshing engines, or steam shovels, coal supplies power through the medium of gas engines, electric automobiles, and storage battery power.

The technology of our manufacturing industries requires, in many aspects, the application of heat or heat treatment. Combustion, baking, calcination, cooking, vitrification, annealing, tempering, vaporization, retorting, are examples of industrial processes requiring heat. In another category is the factor of domestic heat. Approximately one-sixth of the coal mined in this country serves to heat homes and offices.

To the direct and tangible uses of coal must be added the less obvious and somewhat intangible services rendered by this fuel. Rent, for example, represents expenditure of coal in the past, for from the moment the steam-shovel starts the excavation until the last coat of paint is applied, coal is an essential component in the construction of a modern building, each structural material, whether steel or brick, cement or glass, being largely the product of coal burned at furnace, kiln, or factory; the brick and cement on which rent is paid represent one-quarter to one-half their weight in coal, and every ton of metal has cost 2, 3 or even 5 tons of coal. Although appearing but once in this long list of the necessaries and luxuries of life coal is thus an ever-present element in the cost of living.

Origin and Classification of Coal.[1]—Coal is the product of an accumulation of swamp vegetation which grew luxuriantly in a warm climate with an abundant water supply. This vegetation, accumulating over a long period of years, was protected from complete decay and decomposition by a covering of sand and mud under which it was buried. Pressure and heat compressed this water mass of swamp vegetation, or peat, squeezing out the water, and, with the aid of bacterial action, released much of the oxygen and nitrogen. The resulting product is a

[1]For an authoritative discussion of this subject see Bulletin 38 of The U. S. Bureau of Mines, by David White and Reinhardt Theissen, with a chapter on the formation of peat, by C. A. Davis, 1914, 390 pp., 54 pls., discusses the geologic relations of the different coals and the effects of physiographic conditions, rate of deposition. and regional metamorphism, the origin and formation of peat, and the constituents of coal as determined by microscopic study.

highly carbonaceous material with varying quantities of volatile matter, water and ash. Differences in the character of the vegetation, in pressure, in duration of time, and in the intensity of geological disturbance of the coal beds has resulted in a product with the widest extension of physical and chemical characteristics and properties. A division of coal into groups or classes, and a description of the characteristics of each group is essential for an understanding of the economic characteristics and uses of coal. Several methods of classification can be used, depending upon the avenues of approach to the subject. Differences based upon origin, mode of formation, degree of carbonization afford one basis. Classification according to uses is another.

The United States Geological Survey has adopted a method of classification whose basis is founded on differences in the content of fixed carbon, volatile matter, and water in coal. The term "rank" is used to designate these differences, a high-rank coal having a high percentage of fixed carbon and a low percentage of moisture, oxygen, and volatile matter, whereas a low-rank coal is low in fixed carbon and high in the other ingredients. This term must not be confused with "grade" of coal which may refer to the commercial value of any one of the ranks. Thus a "high-rank" coal may be low grade because of a high percentage of undesirable elements such as sulphur or ash. Within the boundaries of the United States there are all ranks of coal, from the coarse, woody lignite of North Dakota and eastern Montana to the highest rank of anthracite in the fields of eastern Pennsylvania.

The ranks established by this classification are anthracite, semi-anthracite, semi-bituminous, bituminous, sub-bituminous, and lignite. There is, however, no sharp line of demarcation between each succeeding rank, the difference being largely a matter of degree of fixed carbon and volatile matter content. Figure 1 shows the comparative heat value and composition of the various ranks of coal.

Anthracite is generally well known and may be defined as a hard coal having a fixed carbon content of over 90 per cent. There is a widespread impression that anthracite has greater heating value than any of the other ranks, but this is not the case, as can be seen by reference to Figure 1. Anthracite is hard, heavy, burns with a short blue flame, and without visible smoke.

Semi-anthracite is also a hard coal, but is not as hard as true anthracite. It ignites more readily than anthracite and burns with a short yellow flame. There is very little of this rank in the country and that which is mined is usually sold as anthracite.

Below the anthracite and semi-anthracite group is semi-bituminous. Coals in this classification are highly desired by the navy because they are practically smokeless. Because of this property as well as their high heating value, they make excellent steaming and bunkering coals. Semi-bituminous is rather low in volatile matter, hence unsuitable for

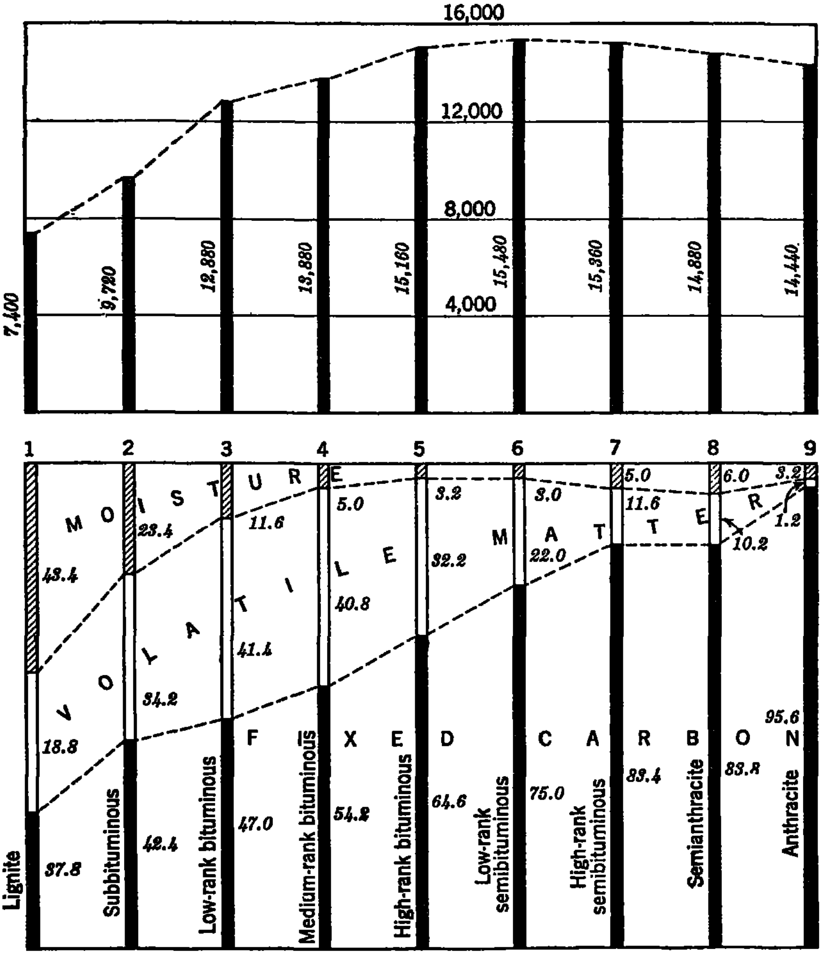

FIG. 1.—DIAGRAM SHOWING THE CHEMICAL COMPOSITION AND HEAT EFFICIENCY OF THE SEVERAL RANKS OF COAL.

Upper diagram: Comparative heat value in B.t.u.'s per pound of the coals represented in the lower diagram, computed on an ash free basis. Lower diagram: Variation, in per cent in the fixed carbon, volatile matter, and moisture of coals of different ranks, from lignite to anthracite, of selected samples.

recovery of by-products. This coal is very friable, a factor which makes it undesirable for domestic heating although very useful in industrial power plants where mechanical stokers are used.

The "bituminous" rank includes a wide range of coals from the poorest western bituminous coal to the high-rank and high-grade deposits in the Appalachian region. Bituminous coal, by reason of its abundance and its excellent qualities, is the real foundation of that great industrial and transportation structure which enables more than a hundred million people to live in America and to be so well supplied with all those things that are necessary for their health, comfort, and convenience.

The sub-bituminous coals comprise a group ranging in appearance and characteristics from the lower grades of bituminous coal to a substance not far removed from the lignites of the northern plains. These coals occur west of the 100th meridian.

The term "lignite" is restricted to those coals which are distinctly brown and either woody or claylike in their appearance. As the moisture of lignite as it comes from the mine generally ranges from 30 per cent to 40 per cent, its heating value is low; and the consumer cannot afford to pay freight for any great distance on so much water. Lignite is mainly marketed near the mine, as a domestic fuel, but at a few places in North Dakota and Texas it is shipped to near-by towns and used for general manufacturing purposes.

Geography of Coal and the Coal Industry.—Coal is found in thirty states from the Appalachians on the east to the Rocky Mountain region in the West; mining operations are carried on in 27 states. New England, the Atlantic seaboard, and the Pacific States (excepting Washington) are conspicuous for a lack of near-by coal supplies. For convenience of description and identification, the coal resources are grouped into provinces, as follows: Eastern, Interior, Gulf, North Great Plains, Rocky Mountain, and Pacific. (See Figure 2.)

The Eastern Coal Province contains probably nine-tenths of the high-rank coal of the country. It is considered as made up of the anthracite regions of Pennsylvania and Rhode Island, the Atlantic Coast region of Virginia and North Carolina, and the great Appalachian region, which embraces all the bituminous and semi-bituminous coal of what is generally known as the Appalachian trough. This region is the greatest storehouse of high-rank coal in the United States, if not in the world. This near-by supply of fuel has constituted the foundation of the development of the blast furnaces, the great iron and steel mills, and the countless manufacturing enterprises of the Eastern States.

Centers of coal production in this field extending from northeastern

[2] Campbell, M. R., The Coal Fields of the United States, Prof. Paper 100-A, U. S. Geol. Survey, 1922, p. 6.

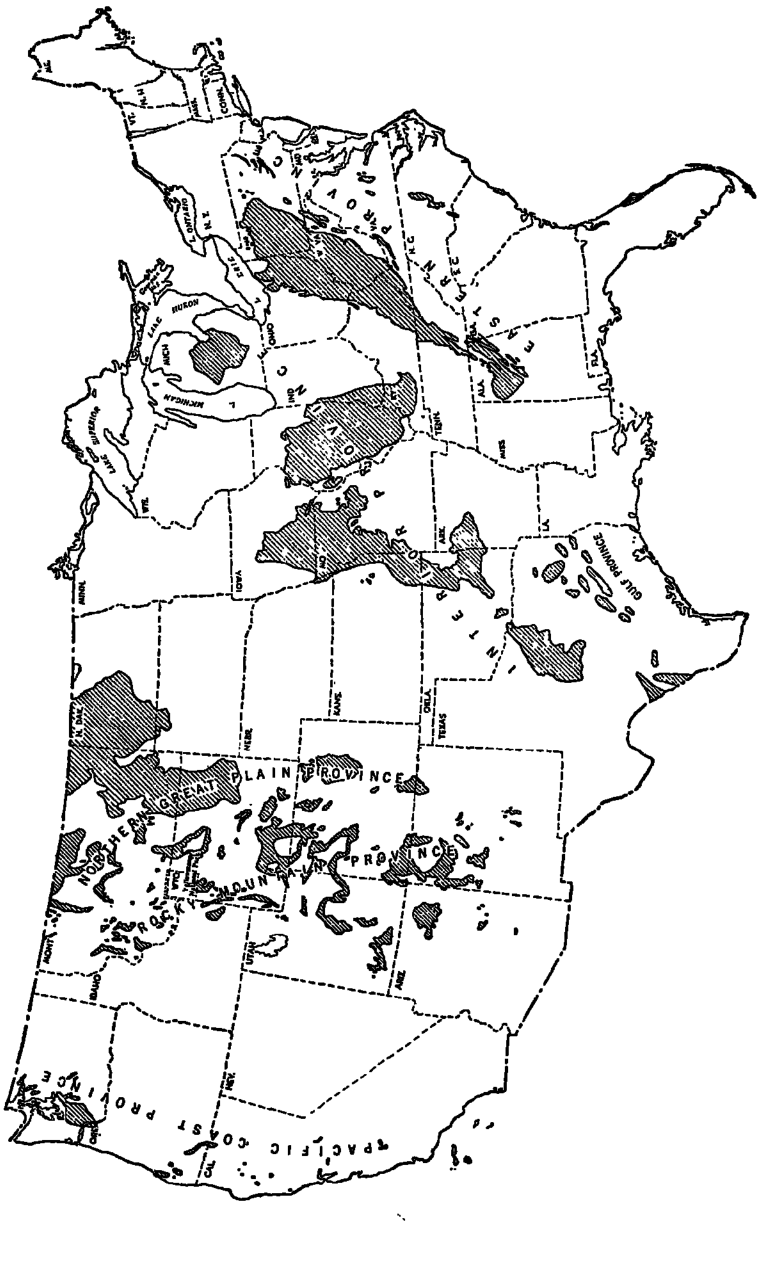

FIG. 2.—COAL FIELDS OF THE UNITED STATES.
The anthracite area occupies a small portion of eastern Pennsylvania.

Pennsylvania to northern Alabama produce three-fourths of all the coal. The important mining centers are localized in eastern and western Pennsylvania (with extensions into Ohio and West Virginia), southern West Virginia, Kentucky, and Alabama. The importance of this field in the industrial and transportational activities of the nation warrant a somewhat detailed description of these more important mining centers.

The Pittsburgh Coal Bed.—Beyond question the Pittsburgh coal bed is the most famous and most remarkable occurrence of high-volatile gas and coking coal in the world. This bed is at the base of the Monongahela group in the upper or Pittsburgh series of the Pennsylvanian system of the Carboniferous Age. It is the most important bituminous coal bed in Pennsylvania, Ohio, and northern West Virginia. It is remarkably persistent over large areas of these states. It ranges in thickness from 16 feet down to 4 feet, generally thicker in the east and south and thins to the west and north; it averages about 7 feet of minable coal.

Original fame attached to the Pittsburgh bed when in the Connelsville region it was early found to make a superior coke in beehive ovens, and along the Monongahela River to the west of the coking region where it outcropped at water level and was of superior quality as a gas coal for steel-making.

> It would be difficult to visualize the large part coal from the Pittsburgh bed has played in the economic development of the United States. The Potomac, with the Chesapeake and the Potomac canal, has acted as an outlet for the Maryland-Pittsburgh bed; the Youghiogheny, Monongahela, and Ohio Rivers afforded cheap transportation for the coal of West Virginia, Pennsylvania, and Ohio, to the broad Mississippi Valley, both northern and southern; the Great Lakes afforded cheap transportation to central Canada and to the far northwest, and the Erie Canal to central and eastern New York and New England. In the early days, canals and a canal railroad over the mountains gave water transportation to eastern Pennsylvania and Maryland and the New York market. Pittsburgh coal early became noted for its excellent qualities as a gas- and coke-making coal, and as strong seam coal. In the early days, gas coal from Westmoreland County was used from the Atlantic seaboard to Chicago in making artificial gas. Coke, especially that from the Connellsville district, served blast furnaces through much of the eastern United States, so that, quite aside from serving as a foundation for the great iron and steel industry of the Pittsburgh district, this coal bed has served the wants of half a nation or more.[3]

At present coal from the Pittsburgh bed serves five principal uses—steam making, including locomotive use, coke making, gas making, and household use. Outside of Pennsylvania its use is confined largely to

[3] White, I. C., et al., The Pittsburgh Coal Bed, Trans., A.I.M.E., Vol. LXXIV, p. 482, 1926.

steam raising and heating. In West Virginia this coal contains too much sulphur for first-class coke.

The production of coal from the Pittsburgh bed has been estimated at about 5,800,000,000 tons since its beginning. The reserves of recoverable coal are estimated at about 22 billion tons. At the recent rate of recovery this bed should last 180 years.[4]

Another important coal deposit in the Pittsburgh district is the Thick Freeport bed. It has an area of 115 square miles and outcrops on both sides of the Allegheny River for short distances. The field has been thoroughly prospected, its boundaries determined, and 16 companies have opened mines. The average thickness of the bed is 86 inches, with an 8-inch band of bone coal in the middle. The coal is used for domestic, by-product coking, and steaming purposes.

West Virginia.—About 150 miles below the Pittsburgh district, lies the second important coal-producing area in the Appalachian coal field, the West Virginia field. On the eastern side of this coal-mining area lie the New River and Pocahontas field famous as a source of the highly prized smokeless coals of high-heating value. Their sootless qualities make them desirable for domestic purposes, and, owing to the great heat content, they are in great demand for naval vessels. To the west lie the Kanawha, Tug River, Logan, Coal River, and Thacker fields yielding coals of high grade.[5]

The topographic characteristics of the region have a marked influence upon the character and extent of mining. The plateau-like country is dissected by numerous streams whose valley sides expose the coal seams. Of these streams, the New River is the one most intimately related to the coal mining industry. Some hundreds of feet above the water level in the valley sides the coal seams are exposed. The coal, when mined and brought to the adit on the valley side, is carried down into the valley bottom by gravity incline. The downward-moving coal-laden cars also haul up the empty cars.

The output in the southern West Virginia region is about 60 million tons annually,[6] equal to one-sixth of the entire Appalachian field. Because of the lack of an industrial development comparable to the Pittsburgh district, coal from this area moves either northward and westward to the Great Lakes ports, or moves eastward to tidewater at Hampton Roads. Approximately 90 per cent of the coal output is exported in this manner to other states.

[4] *Ibid.*, p. 503.

[5] Reger, David B., Smokeless Coals of West Virginia, Coal Age, Vol. 29, No. 18, May 6, 1926, pp. 633–637.

[6] Figures for 1928, Bureau of Mines.

The Alabama Coal Field.—The third field of major importance in the Appalachians is the Birmingham field in north central Alabama. This field, the southern extension of the Appalachian field, widens out from a narrow belt of unimportant and little-valued coal deposits of Tennessee to the north.

In Alabama, the coal measures lie in four different fields, the Plateau, Warrior, Cahaba, and Coosa fields.

The Warrior is the westermost in the district and has an area larger than that of the three other basins combined. Its structure is not greatly broken and the result is that mining can be more economically carried on here than in the other basins. There are six groups of seams in the Warrior basin, two of which, the Pratt and the Mary Lee, account for most of the coal mined in the state. These coals are low in ash and sulphur content, a feature which contributes to their excellence as coking coals.

Coal from the Alabama fields finds its principal market in the iron and steel industries in the vicinity of Birmingham.[7] These industries control the captive mines. Outside of the iron and steel industries the principal consumers are railroads and public utilities. Little coal moves out of the district. Competition from Kentucky and West Virginia have checked expansion to the north; natural gas has curtailed markets in the southwest; fuel oil has taken its toll of the bunker business at the Gulf ports. Even the public utilities market is being threatened by the growth of hydroelectric plants. Coke made from Alabama coal, on the other hand, finds a wide eastern domestic market as well as in shipments to the West Coast and Cuba.

Kentucky.—In this state production is divided between the eastern part of the state lying in the Appalachian Province and western Kentucky which is included in the Eastern Interior Coal Province. The mines of the state are non-union, hence, although farther from the markets, the producers have been able to sell large quantities of coal during strike periods in the Pennsylvania and Illinois fields. The fields in the western part of the state are naturally benefited by a shut-down in Illinois.

The Interior Province.—The Interior Province includes all the bituminous coal fields and regions near the Great Lakes, in the Mississippi Valley, and in Texas. It is made up of four distinct regions—the northern region, in Michigan; the eastern region, embracing parts of Illinois, Indiana, and western Kentucky; the western region, extending across the states of Iowa, Missouri, Kansas, Oklahoma, and Arkansas;

[7] Hall, R. Dawson, The Coal Field That Underwrote Birmingham's Industrial Activity, Coal Age, Vol. 33, No. 10, October, 1928, p. 587.

and the southwestern region in Texas. See Figure 2. As these regions, except one, are not near mountainous uplifts, the coals are of medium rank, for little pressure has been exerted upon them, and their change or devolatilization has been only such as resulted from the long-continued pressure of the overlying rocks. The exception to this is found in the uplifted rocks of the Ouachita mountains in Arkansas where the coal has been devolatilized and approaches a high-grade-bituminous or semi-anthracite rank.

Principal interest centers on the Illinois and Indiana coal fields which together produce 16 per cent of the nation's total output and rank next in importance to the Appalachian field. The coals of Illinois are a part of the Eastern Interior coal field and are estimated to have an area of 35,000 square miles. The principal outlet for this coal is for steam and domestic purposes. Although these coals can be coked, the sulphur content is too high for metallurgical purposes. Certain areas furnish coal suitable for gas making. The presence of these extensive coal fields in near proximity to the agricultural belt and to the avenues of transportation, has been largely instrumental in developing the great manufacturing centers of Chicago, St. Louis, and Kansas City.

Coal of the Gulf Province is of slight commercial importance. This coal is mostly lignite and is mined in a few localities in Texas. Coal of the same rank is found in the Northern Great Plains. The lignite field of this region extends westward into Montana where folding of the rocks has been instrumental in converting the lignite into a sub-bituminous or bituminous rank. The largest coal region in the Great Plains province is the Fort Union region, lying in the Dakotas, Montana, and Wyoming. Many of the coal beds of the Fort Union field are very thick, those that are worked measuring from 3 to 40 feet. In almost every section of land that has been examined, a large number of thick coal beds have been found, indicating that the reserves of coal and lignite must be very large.

There is very little mining in the Fort Union field. An industrial market does not exist. The principal drawback, however, is the poor quality of lignite. Although mining for domestic purposes has been attempted, the lignite cannot compete with high-rank coals imported from the eastern fields.

Further south, in the vicinity of Fort Sheridan, Wyoming, the coal is of higher rank than in the Fort Union field. The community of Sheridan is served by the Burlington railroad. A number of large mines operated on large coal beds range from 8 to 24 feet in thickness. Owing to the cleanliness of the coal, it finds an extensive market for domestic heating.

The leading sources of industrial coal for the Western Interior and Mountain States are in the Raton Mesa field in Colorado and New Mexico. This is one of the most important fields in the west. The coal in the southern part of the region makes excellent coke, and the product of the ovens supplies most of the smelters in Colorado.

The Rocky Mountain Province contains a greater variety of coals than any other province in the United States. The coal ranges from lignite to anthracite and includes all the ranks, though the dominant ranks are sub-bituminous and low-grade bituminous. The principal coal-mining centers are Red Lodge, Montana, Rock Springs, and Kemmerer, Wyoming; Crested Butte and Durango, Colorado; Castlegate and Sunnyside, Utah; and Gallup, New Mexico.

The coal in the **Pacific Coast Province** is limited largely to the State of Washington. Both California and Oregon have small fields within their borders, but the coal is generally of low rank or poor quality, and but little mining has been attempted. Washington, on the other hand, is fairly well supplied with coal in the western part, where it is most needed for the various industries that have been developed around Puget Sound.

The market for Washington coal lies chiefly in the three Pacific States. San Francisco furnishes the largest market, while the railroads of the northwest consume large quantities of the steam coals. The coke manufactured in Washington is of high grade and is consumed by smelters at Tacoma, Everett, and Northport, and in California.

Coal in Alaska.—Alaska contains large reserves of lignite, considerable low-rank bituminous coal, much smaller quantities of high-rank bituminous, and some anthracite. Quantitative estimates are impossible in view of the fact that over 80 per cent of Alaska is unexplored. The known reserves do not equal 1 per cent of the corresponding reserves of the United States proper. Exploitation of Alaskan coal beds is hampered by legal restrictions, by physical difficulties of mining, and by the absence of a local market. There is a small outlet for coking coal in the Pacific Northwest as well as fuel for power generation, although this latter will find expansion difficult as long as California fuel oil dominates the western fuel market.[8]

Canada [9] possesses large deposits of coal chiefly in the Great Plains region with minor quantities in Acadia on the east and on Vancouver Island and in the Rocky Mountain region on the west. Coal is the

[8] Brooks, A. H., The Future of Alaska Mining, U. S. Geol. Survey Bulletin 714, 1921, pp. 43–52.

[9] Patton, M. J., The Coal Resources of Canada, Economic Geography, Vol. 1, 1925, p. 73.

most important product of the mines of the Appalachian and Acadian regions of Canada. With the exception of thin seams in Gaspe, its occurrence is confined to the provinces of New Brunswick and Nova Scotia. This coal possesses excellent steam and coking qualities and has been mined for over 200 years. The known reserves are estimated at 2188 million metric tons.

The lignite and sub-bituminous coal fields of the Prairie Provinces are continuations of similar coal fields in the United States. The deposits are very extensive, some estimates placing them at 15 per cent of the known world's coal reserves. Owing to the favorable competitive position of the coal fields of the United States, the exploitation of these fields has not been very extensive.

The coals of the Rocky Mountain region and the Pacific Coast are bituminous in character. About two-thirds of the present production of British Columbia comes from Vancouver Island. Potentially important coal fields exist in the south central, central, and northern British Columbia.

Both bituminous coal and lignite are found in the basin of the Mackenzie River. The deposits are extensive but the market is limited and production has never exceeded 20,000 tons annually.

CHAPTER V

ANTHRACITE

INCLUDED in the Appalachian Coal Province is that small group of valuable coal deposits in northeastern Pennsylvania—the anthracite fields. The characteristics and uses of anthracite and the organization of the industry differ so markedly from bituminous that this industry should be considered separately.

Anthracite is primarily a domestic fuel. This hard, dense, non-volatile substance burns slowly with little flame and smoke giving off an intense heat which has as yet found no superior among the solid fuels used in the home. House heating has not as yet joined with electric lighting and gas cooking in being supplied by a public utility corporation, and, as long as it remains in the hands of the householder, the manifest need of convenience and cleanliness give anthracite a peculiar advantage. As a result an enormous business of mining, distributing, and retailing this fuel has been built up. There is but a remote relationship between the anthracite business and the industrial activity of the country. A cold climate and a dense population, whether it be industrial, commercial, or agricultural in nature, form the basis of the anthracite markets. As a consequence we find that the greatest outlets are in New England, the Atlantic States, and those sections of the Middle West which are connected with the anthracite mining districts by water transportation. These groups together take over 90 per cent of the total domestic sizes, and with Canada they consume almost 97 per cent.

The location of the anthracite deposits close to the large cities and densely populated states of eastern America explain why so large a proportion of the nation's homes are heated with this fuel.

The anthracite deposits are located in the east central part of the State of Pennsylvania, mainly within Lackawanna, Luzerne, Carbon, Schuylkill, and Northumberland counties. In these five counties, anthracite mining is the dominant and characteristic industry. There is some overlapping of the anthracite beds into Wayne, Susquehanna, Wyoming, Sullivan, Columbia, Dauphin, and Lebanon counties. The region embraces a territory of 3300 square miles, but less than one-fifth of this total area is underlain by workable coal measures. These are grouped in 4 major coal fields and 17 mining districts. If all of the coal regions were brought together they would form only a small area, about 20 by 24 miles, an area which appears insignificant when compared with the vast dimensions of the bituminous coal fields. It is only on a basis of number and thickness of the coal seams, the quantity of coal per acre, and the commercial value of the coals, that a proper conception of the magnitude of the anthracite industry can be had.

The usual shape and structure of all the anthracite tracts is that of long and irregular basins. They have doubtless assumed this form from the elevation, on all sides of them, of the underlying rocks of the country in a series of nearly parallel belts. The coal strata are found only in the intermediate spaces between the lines of upheaval, in these basins or troughs, the strata dipping from both margins inward, sometimes at a high angle, caused by the tilting upward of the underlying formations, and the destruction, by the action of water, of the broken portions of the coal strata which once covered the upheaved intervals between the coal basins. There is but little doubt that all the anthracite fields are but several portions of one great formation which, previous to assuming the basin-like form, constituted a single continuous body or mass of strata. It is estimated that only 6 per cent of the original deposits were left for the use of man.[1] The upfolding of the bedded layers of rock and coal, and subsequent denudation by water, fixed the limits and produced the form and the singular positions and disturbances of the anthracite regions.

Anthracite Reserves.—The reserves of anthracite are estimated at 21,000,000,000 *tons.*[2] *In making this estimate* Campbell used the same assumptions as to what constitutes a reserve as are applied to the bituminous fields (see section on bituminous coal). Such estimates must always be subject to qualification. A reserve may be considered as that body of coal that can be mined profitably. To distinguish this from the physical quantity of coal in the earth, it may be termed the "economic reserve." Present mining methods and present prices are the conditions determining the extent of the existing economic reserve. A change in the set of conditions, e.g., reduction in the cost of mining, or an increase in price, may bring hitherto unprofitable coal bodies across the line into the economic reserve. On the other hand, the appearance of a substitute for anthracite, deliverable to the consumer

[1] Keystone Catalog, 1928.

[2] Campbell, M. R., The Coal Fields of the United States, Prof. Paper 100-A, U. S. Geological Survey, 1922, p. 24.

at a substantially lower price, may serve to reduce the economic reserve or even cause it to disappear altogether. The possibility of such competitors to anthracite appearing on the market is discussed elsewhere.

Mining Methods.—The geologic surroundings of the beds determine to a large extent the method of mining that must be employed for the recovery of anthracite. Where beds are flat, a room-and-pillar method can be used, similar to that employed in the bituminous coal fields. Where roof conditions permit, long-walled mining can be undertaken. Where the coal does not have much cover it is possible to remove the surface and mine the coal with power shovels. This kind of mining is known as "stripping." Where the beds pitch steeply, the breast system of mining is employed almost exclusively. The present method of breast mining is to drive a gangway in the rock below the coal, drive a rock-chute from the gangway to the bottom of the coal, connect rock-chutes with headings in the coal for the circulation of air, and then, on 50- to 60-foot centers, drive breasts up the pitch, making the breast 18 to 24 feet wide. Timbers are so placed along the sides of the breast as they are driven up that the coal as it is mined falls between the two rows of timbers, and is held from running out the mouth of the breast by a battery. As fast as coal is shot down, it is drawn from the bottom of the breast through chutes to maintain just enough head room between the top of the loose coal and the face of the breast to permit the men to work. The spaces between the timbering and the breast and the ribs of the pillars are used for the circulation of air to the face; also as manways for the men to pass to and from their work.

This method of mining, requiring much hand work, necessarily makes a high labor cost. The average output of coal per man per day is somewhat less than 2 tons (1918–27 average),[3] whereas in the bituminous industry the per man per day output is as high as four tons, and has shown a gradual improvement in the past years. The miner's wage represents as high as 70 per cent of the f.o.b. mine cost of coal. Natural conditions in the anthracite mines have not favored the introduction of cutting machines which account for less than 2 per cent of the mine output. Strip mining also is unimportant in the total yield. There is little indication that substantial economies can be effected in mining operations since extensive mechanization is precluded by the geologic nature of the beds.

Preparation of Anthracite.—Anthracite mining, much more than bituminous, is a manufacturing as well as an extractive industry. The product as it comes from the mines ordinarily contains large quantities

[3] Kiessling, O. E., and Bennett, H. L., Anthracite in 1927, U. S. Bureau of Mines, p. 4.

of slate, rock, and other impurities. The coal, therefore, must be put through an elaborate mechanical process by which the refuse is removed and the coal broken into various market sizes. We have seen that the daily output of the anthracite miner is smaller than that of the bituminous worker, resulting in a higher labor cost per ton. To this must now be added the labor cost of the men who prepare the product for the market. In an anthracite mine it is the rule to mine all the available beds from one opening, so that at some breakers coal from as many as ten seams may pass over the screens. Obviously, no attempt is made to separate the coal from one seam from that of another and, in fact there is so little difference in the analysis and hardness of coals from the various seams in the same locality that nothing would be gained by such a process. The preparation of anthracite begins at the working face at which point the miner removes all possible rock from the coal sent to the surface, although, because of the intimate mixture of slate and coal in the seams, the miner is permitted to send to the surface, without penalty, from 100 to 500 pounds of rock in each mine car. Anthracite as it comes from the mines is in a state that is not fit for consumption because of these included impurities. To convert it into a marketable commodity, the coal is treated in breakers, those large black buildings that dot the landscape throughout the anthracite fields. Here the coal is crushed and the slate and refuse sorted out, after which it passes over a series of screens which separate it into the several market sizes: grate, egg, stove, chestnut, pea, and buckwheat.

The Cost of Anthracite.—The steady rise in the retail price of anthracite and the wide difference in price between it and bituminous coal are of keen interest to the householder, the principal consumer of anthracite. The elements entering into the cost of anthracite, in addition to mining and preparation costs, constitute transportation, royalties, overhead, and distribution, retail and wholesale. The first of these, for reasons mentioned, are higher than for bituminous coal. A considerable portion of the anthracite is mined by the so-called "independents" under leases in which the operator pays the landowner a royalty, these ranging from 12 cents to $1.50 per ton. The "railroad" companies for the most part own their coal lands in fee simple, and royalties do not enter into the cost of production. Transportation is a considerable item in the ultimate cost. The Coal Commission found that 16 to 40 per cent of the retail price is represented by transportation. This has been a very profitable business for the railroads, and the existing freight rates have been a point of criticism by those who have insisted that the cost of carrying is too high. Other factors that may be mentioned as having a bearing on cost of production, and ultimate price, is irregularity of operation, and a lack of scientific management in the productive process.

These elements are not sufficient, however, to explain the prevailing high prices. The element of control of production and competition must be considered. The conditions which gave rise to monopoly in the industry are: A limited supply in a restricted geographic area, the coal lands owned by a small number of corporations, estates and individuals who seldom offer even small tracts for sale: unified control by eight interests and affiliated corporations;[4] and, until recently, a unified

Producing Companies	Railroad
Philadelphia and Reading Coal and Iron Co.	Philadelphia & Reading Ry. Co.
Glen Alden Coal Co.	Delaware, Lackawanna & Western R. R. Co.
Hudson Coal Company.	Delaware and Hudson Co.
Lehigh Valley Coal Co. Coxe Bros. & Co. (Inc.)	Lehigh Valley R. R. Co.
Pennsylvania Coal Co. Hillside Coal & Iron Co.	Erie R. R. Co.
Lehigh and Wilkes-Barre Coal Co.	Central Railroad Co. of New Jersey.
Lehigh Coal & Navigation Co.	Lehigh and New England R. R. Co.
Scranton Coal Co.	New York, Ontario & Western Ry. Co.

The list contains 8 railroads and 10 coal companies. The Lehigh Valley Coal Co. and Coxe Bros. may be thought of either as two corporations with separate cost records and income and investment accounts, or as a single "interest." Likewise, the Pennsylvania Coal Co. and the Hillside Coal and Iron Co. may be thought of either as two corporations or as one interest. In this way the group of railroad companies may sometimes be referred to as "ten companies," and sometimes as "eight interests."

control of mine labor. Stabilization in the industry and restriction of competition were accomplished by pooling of traffic, limitation of output, and other devices. There was a close degree of cooperation among the railroads through their ownership of coal-mining and coal-selling companies. It was obvious that a company which operated a railroad and also mined coal on its lands had an advantage over other coal-mining companies that were compelled to use the same railroad, and that if the several railroads that center the coal regions were to combine, this advantage would become economically irresistible. Although the Supreme Court, in 1908, ordered the separation of coal companies from the railroads, the close cooperation of the coal and rail interests apparently continued, and have since steadily gained over the "independents" in the proportion of total coal output.

[4] The anthracite "railroad coal companies," together with the railroads with which they are or were affiliated, are as follows:

Moreover, the circular prices of coal have varied by little among the large "railroad" companies in spite of the fact that, because of great variation in physical conditions, certain large companies have costs as much as two dollars below the costs of other companies less fortunately situated. The effect of this price policy is to allow the high-cost producers to fix the price while the low-cost operators reap a large profit.

If there be a monopoly in effect it is not in the sense of pooling cost and profit among the railroad companies but in the sense that practically uniform prices have been charged by the railroad group. From the consumer's point of view, the retailer in his purchase of railroad company coal might about as well be dealing with a single corporation with a single price.

Although it has been suggested that a reduction in the price of coal could be effected by freer competition and greater output by the low-cost mines, it is not likely that the desired end will be accomplished in that way. The public may hope for more favorable prices through the introduction of substitute and competitive fuels. The recent strikes, beginning about 1917, have had their effects upon consumers who were compelled to use substitutes. The strike of the summer of 1925 was met by an unusual degree of substitution by bituminous coal, fuel oil, and briquets, resulting in a permanent loss of markets to the anthracite industry. The average output of 80 million tons for the years previous to the strike declined to a level of 75 million tons in the ensuing years, 1926–29.

Raw bituminous coal, fuel oil, and coke have made inroads on the anthracite markets. Although the data available do not permit a forecast of the future trend in domestic fuel consumption, it may be pointed out that the prevailing high prices of anthracite, in the face of a 10 per cent decline in demand, will stimulate the producers of substitutes. Coke manufacturers are not oblivious to the possibility of capturing part of this market, and the heating of urban homes by gas is a possibility with which to reckon. The study of effective fuel utilization, which has produced such remarkable results in power generation and industrial uses may, if applied to the domestic field, make available substitutes obtainable from bituminous coal. Such an event would spell the passing of anthracite as the sole, or principal, source of domestic fuel.

CHAPTER VI

ORGANIZATION OF THE COAL INDUSTRY

Production and Preparation.—Coal mining is carried on by a large number of independent, competing companies distributed widely in each of the major coal producing fields. The largest companies each account for but a small share of the total output. No single company or group is dominant in the industry.[1] Of the 7000 mines in operation (1928), 132 companies produced over 500,000 tons each, and in the aggregate these accounted for 18 per cent of the year's output. On the other hand, there were 2700 mines, producing less than 10,000 tons yearly with an aggregate output of less than 2 per cent of all coal mined.[2]

The fundamental conditions responsible for the development of the coal industry in this manner are the wide geographic distribution of the coal fields, easy access to coal beds, and frequent outcroppings of coal seams, together with a demand for fuel in every community and district of the country. The ease of exploitation engendered by the geographic and geologic characteristics of coal deposits also explains to some extent the keen competition, over-development, irregularity of production, etc., attendant to the coal industry to-day and is the basic cause of its many tribulations.

The art of mining is one of long development. The first coal miner, no doubt, picked coal from the surface of the ground or from an outcrop on the valley side. When, however, the surface supplies disappeared, and it became necessary to go underground, simple tasks became complex; specialization developed. The real miner became a crafts-

[1] This does not apply to the anthracite industry.

[2] Capacity (Tons)	Number of Mines	Per Cent of Total Mines	Per Cent of Total Output
Over 500,000	132	1.9	18.1
200,000–500,000	647	9.2	36.7
100,000–200,000	818	11.7	22.3
50,000–100,000	879	12.5	12.3
10,000–50,000	1831	26.1	8.9
Less than 10,000	2704	30.6	1.7

man in the hazardous task of winning coal from the earth. The functions of mining and hauling coal to the surface became separated. Systematic working of a coal seam became necessary. Gradually a code or set of arrangements evolved which assigned definite duties and privileges to the several factors of the mining procedure. The pivotal man on the scheme of operations is the skilled miner. He is set apart from wage men engaged in auxiliary tasks such as pumping, hoisting, tracklaying, haulage, etc. These men are, in a sense, the miner's helpers. The miner is virtually a subcontractor under the mine operator. His compensation is proportional to his daily output of coal. The system of mining which developed was a response to the individuality of the miner.

The common systems of mining that have developed are known as the "room-and-pillar" system (with its many variations) and the "long-wall" system. In the former system a main tunnel from the outside enters the coal seam. From this main entry lateral tunnels are cut usually at right angles to the former, and from these lateral tunnels the miner works making long openings called rooms. Between the rooms blocks of coal are left intact to support the roof. These are known as pillars. The entries and rooms are protected by mine timbers placed vertically to prevent the mine roof from caving in. As the mine is worked out the pillars are systematically removed as far as it is possible to do so without endangering the safety of the miner.

In the long-wall method of mining, the coal is removed from a more or less continuous line of breast or working surface. The mined-out space is filled with rock or sand to support the roof. The coal is usually removed without blasting, being undermined and then broken by the roof pressure.

Coal is removed from the working face or breast by hand mining, by "shooting from the solid," or by machine cutting. Where mining is done by hand, the miner accomplishes his round of duties necessary to the removal of coal with relatively small investment in tools. The "overhead" is low. The principal element of cost in coal production is the miner's wage.

The term "shooting from the solid" is used to describe a method of working in which coal is blasted from a solid face without previous undercutting. It is used extensively in anthracite mining and to a limited extent in bituminous mines. The chief labor in production of coal by this method is drilling of the holes for powder and the loading of the coal into mine cars. This method, like hand mining, is declining in importance.

The introduction of mechanical devices in coal mining is effecting profound changes in the mining industry. The increased productivity of the miner using machines, in spite of the higher fixed investment and overhead, is gradually replacing hand-mining methods. Mechanization of mining applies to two distinct operations, viz., removal of the coal from the working face of the seam, and loading coal into mine cars by mechanical loaders instead of by hand shoveling. The former is accomplished by coal-cutting machines which have served to increase manyfold the productivity of the miner and the capacity of the mine.

The importance of machine cutting has gradually risen from less than 50 per cent in 1911 to 75 per cent in 1926. During this time the number of undercutting machines has shown no increase but the average output per machine has nearly doubled.

The mechanization of the coal-mining industry, as represented by the extent to which coal-cutting machines have supplanted hand mining and "shooting from the solid," is also showing signs of application to coal loading. This task, when performed by hand, represents an enormous expenditure of human energy.[3] That such a method will remain unchanged in a mechanized era such as we see to-day is hardly credible. Machine loading, although still almost in the experimental stage, is showing remarkable progress.

From approximately two million tons in 1923, the handling of bituminous coal by loading machines has increased to over 21 million tons in 1928. This refers only to coal loaded entirely without the aid of hand shoveling and does not include hand-loading conveyors and mine-car loaders. It should be remembered, however, that such hand-loading devices reduce the height to which coal must be lifted by the miner and, in consequence, effect saving of labor. The tardiness in the adoption of loading machines is explained by the unusual difficulties experienced in devising machines to meet the diverse conditions underground together with the problem of coordinating the loading machines with the underground haulage system. Mechanical coal loading, no doubt, will experience, in the next decade or two, the same progress that has been observed in mechanical cutting. With it will come a rearrangement of the factors of production. The technique of modern factory production with division of labor and machine operation will replace the traditional method of hand mining by independent miners.

[3] Hamilton, W. H., and Wright, H., "A technician, with regard only for the mechanics of the operation calculates that human effort thus applied is only 2½ per cent efficient and is paid for at the rate of $10 per kilowatt-hour. An ore engineer estimates that the coal we burn in two months would fill the Panama Canal; yet in a year our miners use sheer human muscle in loading coal enough to fill it six times over." The Case of Bituminous Coal, p. 119, 1925.

The loading machine will take its place among the several mechanical tools or machines which will make up a coordinated system for the mechanical mining of coal and bringing it to the tipple or the railroad siding.

An appraisal of the economic consequences of machine loading would be premature in view of the experimental nature of the undertaking. Data from mines in several states seem to show a considerable increase in productivity per man as well as a longer working year in the mines equipped with loading machines.[4]

Coal Preparation.—Upon leaving the mines, bituminous coal requires a relatively simple process of preparation before delivery to the market. The principal treatment is to screen the coal for separation of sizes and the removal of dirt and rock. Sizing is effected by screens after which the coal is passed over picking tables for the removal by hand of rock and bony coal.

Distribution of Coal.—The major movements of bituminous coal to areas outside of the industrial district of Pennsylvania and Ohio is toward the Atlantic Seaboard and New England, to the Lake States, and into Canada with minor exports to other foreign countries.

The Atlantic Seaboard and New England trade moves through Hampton Roads, New York, Philadelphia, Baltimore, and Charleston. Hampton Roads is the principal distribution center for coal from the West Virginia fields while the Pennsylvania fields ship their coal mainly through the port of New York or by rail through the northern part of the state.

The lake coal trade has its origin in several mining districts in the Appalachian field and is served by numerous railroads. The Pittsburgh and Connellsville districts of western Pennsylvania and the Fairmont, Pocahontas, New River, and Kanawha districts of West Virginia are the principal sources. This coal moves to nine Lake Erie ports where it is transferred to lake steamers. Transfer to the vessels from the railroad is accomplished by coal-loading machines. Unloading is also a machine operation, the huge steel unloading buckets, motivated by electricity, empty the vessels in record time.

Lake coal goes to all the principal ports on Lake Michigan, Superior, Georgian Bay, and to ports reached through the Welland Canal and the St. Lawrence River.

[4] Tryon et al., Coal in 1927, pp. 382, 383.

CHAPTER VII

COAL INDUSTRIES AND MARKETS

COAL enters the energy market in competition with fuel oil, gasoline, natural gas, water power, and even, to some extent, wood. This competition takes on varying forms and degrees. Most directly, perhaps, is the competition between coal and fuel oil. The latter has made serious inroads on the coal bunker market with consequent reactions on the coal bunkering trade in the American as well as the British coal fields. In the railroads and the public utilities this competition is also extensive but less direct, inasmuch as the principal oil users are in the West and Southwest distant from the coal fields and nearer the water power zones. The competition of gasoline is less evident but none the less existent. The wide use of the automobile is definitely curtailing the passenger traffic on street and interurban railways with the result that lines are being abandoned. The competition from natural gas is accomplished indirectly through the substitution of the gas for fuel oil in petroleum production and refinery operations, thereby releasing the latter for other industrial uses. Water power competition varies with each locality. In the Southeast, for example, it has actually brought about a decrease in coal demand by public utilities, while in the industrial northeast, hydro-electric energy supplies a a large share of the market that would otherwise be filled by coal.

The factors that determine the competitive position of coal are sometimes geographic, sometimes inherent in the nature of the fuel itself. The most intensive market areas are in western Pennsylvania, Ohio, Michigan, and the industrial area of the southern Appalachians. North and east coal meets the competition of water power. In the bunker trade of the Atlantic Seaboard and in the industrial area surrounding Chicago, fuel oil is a serious competitor. In the West it gives up the field to fuel oil, natural gas, and water power.

The progress of engineering is continually changing the relative values of these competing energy groups. The science of steam engineering is wiping out many of the early advantages held by water power over coal. The technology of oil refining promises to alter the competitive relation between coal and fuel oil. The swift expansion of natural gas has disturbed the equilibrium of existing energy markets.

A product of the struggle for position among the energy resources is resulting in greater economy, better utilization and lower power and heat costs.

A survey of coal consumption, by uses, reveals certain characteristics which throw light upon the nature and extent of the coal market. The consumer groups may be roughly divided into: The railroads, electric utilities, coke and gas manufacture, general manufacturing, and domestic fuel. Their importance as coal users is indicated by the following percentages for the year, 1927, a year of normal industrial activity:

	Per Cent
Railroad fuel	27.7
Coke ovens, including coal and water gas	17.0
Electric utilities	7.7
Steel works	5.4
General manufactures	19.5
Mines and quarries	1.9
Bunker coal	1.5
Domestic and all other	19.3

The wide diversity of coal-using industries founded on coal has its origin in the universal need for industrial heat and power. The materials for heat and power production take on various forms such as coke, briquets, pulverized fuel, coal gas, or water gas, but each of these has its origin in raw coal. Of these fuels *coke* occupies a strategic position and may be regarded as one of the key fuels in the industrial structure.

Coke.—Coke reduces the raw metallic ores of nature into usable forms and thus lays the foundation upon which the superstructure of modern industrial production is built.

Coke is produced in the United States by a group of four industries which are related in the sense that the product is more or less interchangeable, but which are sharply differentiated as to location, methods, equipment, and organization. Besides that produced in the familiar beehive and by-product ovens, coke is obtained in the refining of petroleum and in the manufacture of coal gas.

The petroleum coke may be dismissed with a word. In refining crude oil the ultimate residue left in the stills is a porous, carbonaceous solid, which is broken up into chunks and removed from the stills. Its properties are much like those of coke made from coal, except that it is finer in texture and lacks the strength required for metallurgical coke. The best petroleum coke is extremely low in ash content—a quality which adapts it to the manufacture of carbon electrodes.

In the coal-gas industry, as in petroleum refining, the coke obtained is a by-product. The process of manufacture is essentially the same as that in by-product coke ovens, though the type of oven is very different. The coals used are selected for their yield in gas rather than for their coking qualities, and the coke formed is too soft for furnace or foundry use. It is, however, well adapted to the manufacture of water gas, a fact which has led to the common association of coal-gas and water-gas plants as parts of the same city supply. Neither petroleum coke nor gas-house coke is adapted for metallurgical purposes—the use which consumes over 80 per cent of all the coke produced. Practically speaking, therefore, the coke trade is concerned only with beehive and by-product coke.

Coke may be described as the solid carbonaceous product remaining after coal has been subjected to destructive distillation to drive off water and volatile matter. The distilling process leaves a substance which is hard and porous. The porosity of the coke means a very large surface for a given quantity of coke which characteristic permits rapid burning of the material with consequent high temperatures—a feature which is highly desirable in metallurgical work. Although the most important outlet for coke is in the smelting of ores, it is also used in gas manufacture, in foundry practice, and in domestic heating.

The essential qualities of metallurgical coke are hardness and strength, rapid burning, with a low phosphorus and sulphur content. For the production of a fuel with these characteristics a proper kind of coal must be obtained. Not all coals can be made into the superior type of coke that will give satisfactory results in the blast furnace. For beehive coke the best results have been obtained from coal having about 32 per cent volatile matter. Variations from this proportion of volatile matter yield a coke which is brittle and easily crushed, hence lacking in strength for blast furnace use. For the more modern method of coke manufacture, the by-product process, a lower volatile content is permissible, some of the favorite coking coals obtained from the Pocahontas and New River fields of West Virginia having less than 20 per cent volatile content.

The coking coals of the United States are obtained mainly from the high-grade bituminous rank coals of the Appalachian field. The Pittsburgh and Freeport coal beds have been mentioned in connection with the industry of Pittsburgh. The beehive coke from the Connellsville district is still considered the standard coke of the country, cokes from all other sections being judged in comparison with it. The coal from the Connellsville district contains approximately 32 per cent volatile matter, the proportion and composition of which seem to favor its distillation in the beehive oven at a temperature and rate that favor a maximum yield of coke with a minimum loss of fixed carbon. This coal can be charged into the coking ovens without any special preparation.

West Virginia has coal of exceptional purity, and, where proper attention is given to preparation of the coal and the operation of the ovens themselves, a coke of superior chemical and physical properties is produced.

Coals from the southern part of the Appalachian field, comprising eastern Kentucky, and the States of Tennessee and Alabama must be washed before coking. The coke is of a poorer quality, and its ash and sulphur content are high.

The important iron-producing states of Illinois and Indiana have very limited supplies of coking coal. In the western coal fields, deposits of coking quality are found in Colorado, New Mexico, Utah, and Washington.

The Evolution of Coke Manufacture.—The essential principle in coke manufacture is the destructive distillation of coal, that is, heating coal in the absence of air, to separate the volatile content from the solid carbon. Early methods of coke manufacture were exceedingly crude and gauged by present-day methods, also wasteful. The coking of coal in mounds or piles is an example of the early efforts at coke manufacture. Although this is no longer done, it did produce an excellent quality of coke. Reports show, however, that it was lacking in uniformity and that the yield was low.[1]

The Beehive Oven.—The commercial development of coke making may be regarded as beginning with the introduction of the beehive oven. The essential features of the beehive oven are a circular, vaulted, fire-brick chamber constructed on a flat tile foundation, with an opening in the top through which the coal is charged and the products of combustion escape, and an arched door at the bottom through which air is admitted and coke withdrawn. The heat for the coking process is supplied by the burning in the chamber of the distilled gases. The heat from the previous charge, held by the brick, raises the temperature to the point where the volatile matter distilled from the coal finally ignites.

The beehive oven was supreme in the field from 1860 to 1918. This type of oven is well adapted to pioneering. It can be built in remote mining camps, where even a seam of coking coal crops out, to supply an infant iron or copper industry. To avoid the cost of transportation on that part of the coal that is not converted into coke, the ovens are located at the mines. There is no recovery of by-products and usually

[1] Belden, A. W., Metallurgical Coke, Tech. Paper 50, U. S. Bureau of Mines, 1913, p. 8.

no market for the breeze and fines produced. The capital investment per oven is small, and the time required to construct an oven is brief. Each oven is a unit, and coke may be made on any scale, large or small. Although there have been large consolidations of beehive operations, notable in the Connellsville district, the incentive toward amalagamation was perhaps more the acquisition of reserves of coking coal than the unification of oven operation. The beehive oven is easily started up and as easily shut down. Deterioration from exposure to the elements is small and simply repaired. Producing coal of excellent quality for general use and therefore able to ship coal when coke is not in demand, the beehive operator is not confined to coke as his sole source of revenue. All these factors combine to make the overhead charges in beehive operation small and to adapt the industry to the fluctuating demand which has been a feature of the business.

Certain disadvantages in beehive operation eventually compelled it to relinquish its dominant position in the industry to its more elaborate successor. This older type of oven is very exacting in its raw coal requirements. Moreover, the volatile matter, escaping from the ovens in the process of coking, represents a loss of valuable products recoverable in the by-product oven. A ton of bituminous coal coked in a beehive oven will yield about 1300 pounds of metallurgical coke whereas the same amount of coal, coked in a by-product oven, will yield 1500 pounds of coke of equally good grade, together with about 22 pounds of ammonium sulphate, 9 gallons of tar, 2½ gallons of light motor oil, and 10,000 cubic feet of gas. The improvements of coke oven technology and a growing value of the recoverable by-products paved the way for the rise of the modern type oven.

The By-Product Oven.—The modern by-product oven is a rectangular airtight retort in which bituminous coal is distilled, in the absence of air, to such a temperature that the volatile matter will be completely separated from the fixed carbon. The process is under control and can be nicely regulated. Heat is supplied by burning the gas from the coal in flues surrounding the oven.

Manufacture of by-product coke typifies large-scale modern industrialism. The by-product plant, with its intricately designed retort ovens, its use of power and machinery, its apparatus for by-product recovery, its tar and benzol stills, is essentially a chemical factory. It must be located near the point where the first among the by-products—gas—is to be used, ordinarily near some large center of population. Not only are the volatile products in the gas recovered, but maximum efficiency in the utilization of fines and other wastes is possible. The by-product plant requires technical skill of the highest order, large initial investment, and large operating units. All these things mean heavy overhead expenses per ton of coke produced and put a premium on continuous operation.

The two methods of coke manufacture were long engaged in competition. On the continent of Europe beehive coking went out of existence years ago, but in the United States, up until about 1905, less than 10 per cent of all coke was produced in by-product ovens. Since that time, however, the growth has been rapid until the output has risen to an average of 80 per cent of the total in the post-war years.

During the early years of by-product operation in this country there was always a question as to whether by-product coke was as satisfactory for metallurgical fuel as beehive coke. As a consequence, the development of by-product ovens required a study of the use of this fuel in blast furnaces, but it has now been thoroughly demonstrated by long experience to be at least as good as beehive coke for practically all the applications to which either is put, and under some conditions it is even better.

The limitation upon substitution of by-product ovens for beehive ovens has been largely that of conservatism in making new investments. The investment in a by-product plant is so much greater than in a beehive plant of the same capacity that regular operation for a considerable period of time must be assured before a change from a beehive to a by-product plant is justified. Other causes that have retarded the installation of retort ovens has been the small demand for many of the by-products in America. The ammonia could easily be marketed, but the lack of a dyestuffs industry meant small demand for the group of benzol products and low prices for tar. No less important was the absence of markets for gas near the chief centers of steel manufacture. In the Pittsburgh district by-product oven gas had to meet the competition from natural gas, which is superior in heating efficiency and for many years was available in unlimited quantity at exceedingly low prices. The very fact that the population is less dense in the United States than in Europe operated to discourage the recovery of by-products here. Moreover, the violent fluctuations in the production of iron and steel and consequently in the demand for coke, more marked in the United States than in Europe, were less of a handicap to the beehive industry, with its low overhead charges, than to the by-product plants, where continuous operation was essential to profits. Not least among these forces has been the prodigality of the nation's resources of fuel, which made it cheaper to mine more coal than to use efficiently that already mined.

Despite the factors indicated above, the by-product industry has risen to an average of 80 per cent of the output at which figure it has substantially remained for a decade. The manufacture of the remaining 20 per cent by beehive ovens assumes more and more the character of an auxiliary supply called upon to furnish only peak requirements of the metallurgical industry in times of active business.

Gas, like coke, is the product of several industries of widely differing characteristics and purposes. The principal sources of gas are the natural supply, of which this country has an abundance, and from coal, from which it is manufactured either as a primary product, or is obtained as a by-product. Minor sources of gas are obtained from blast-furnace operation and from oil cracking. The natural gas industry, its present importance and future prospects, is reserved for discussion in the chapter on oil and gas and will be dismissed for the present with the statement that its relative importance in the gas industry is declining.

Manufactured gas bids fair to occupy an increasingly important position as fuel for industrial use and in field of domestic cooking and heating. The most important use of gas in an earlier day, as illuminant in homes and on streets, has been succeeded by electricity. In this connection the reader will, no doubt, recall the glowing prophecies of a time when the magic wand of electricity would also replace gas in the cooking and heating services. Far from becoming a moribund industry, however, gas is making rapid strides as a heating agent both in the domestic and industrial fields, and, with each improvement in technology of production and distribution, it is taking a more important position among the fuels.

In many respects gas is an ideal heating agent. Cleanliness, absence of ashes, nicety of control, intense heat, more effective use of heat content, all favor gas as a form of fuel when the aim is to secure heat rather than power. Gas cannot replace electricity as a form of power distribution or a lighting agent. The ease, convenience, and effectiveness of the latter, as well as the distances over which electrical power can be transmitted and applied in small units cannot be approached by gas. On the other hand, electricity as a source of heat is not a competitor of gas. Ramsburg [2] points out that whereas the useful heat obtainable from electricity is equal to 16 per cent of the heat content of the coal used to generate the electricity, this same quantity of coal can deliver effectively 60 per cent of its heat content in the form of gaseous fuel.

Gas also promises to be an important factor in refrigeration, and may eventually be utilized in cooling homes in summer.

[2] Ramsburg, C. J., A Revolutionary Improvement in Gas Production, Proc. of the International Conference on Bituminous Coal, 1926, p. 514.

Gas as a raw material for synthetic chemical products may have far-reaching importance.

The use of gas in homes is so obvious that it needs no comment. In the field of industry gas is rapidly increasing in favor.

The ceramics industry probably furnishes one of the most profitable fields for gas utilities. The principal use of gas is in the enamel, glass, heavy clay products, refactories, and white wares divisions. Gas is the ideal fuel for such purposes because of its adaptability to accurate temperature and furnace atmosphere control. The question of heat is of great importance in the ceramic industry as the cost of fuel is from 10 to 25 per cent of the total cost of production in the majority of its branches.

Gas is a very important factor in the manufacture of glass and glass products. A partial list of glass products include sheet glass, plate glass, decorative glass, tableware, ovenware, illuminating refractories and globes, lamp chimneys, auto lenses, glass lamps, door and furniture knobs, electric instrument covers, electrical insulators, tubing, jars and food containers, and bottles.

All heat operations in the manufacture of steel and steel products and in the treatment of metal are being done with gas. These include open-hearth furnace melting, forging, normalizing, annealing, hardening, tempering, carbonizing, etc. The trend of industry toward the use of automatic equipment for heat-treating operations is realized and gas, because of its adaptability to automatic operations, is being used extensively.

The principal commercial gases derived from coal are coal gas, water gas, coke oven gas, producer gas, and blast furnace gas.

Blast furnace gas is a by-product of the smelting of iron ore and is used mainly in supplying power at the smelter or it may be piped to a steel plant where it is used as fuel in open-hearth steel manufacture.

Coal gas is derived directly from bituminous coal by distillation in a closed retort, the gas being driven from the coal leaving a coke residue in the retorts. The coke is sold direct as hard fuel, or may be used as a raw material for the manufacture of water gas. The heating value of the coal gas produced by this process is under control and may be varied from 500 B.t.u. up to 650 or more per cubic foot. Best results are secured when the production of gas is carried on at a fairly uniform rate, as the process does not lend itself readily to intermittent operation.

Coke oven gas is a by-product of the coke industry. Its total output is small compared with coal gas or water gas. It is used largely in open-hearth steel manufacture or as an auxiliary source of supply by a city gas company where the coke oven is conveniently located. The manufacture of coke oven gas is also essentially a continuous process with little flexibility in the rate of production.

Blue water gas is produced by passing live steam through incandescent coke. This is an intermittent process, the coke first being made white hot by forcing a blast of air through it, after which the air is shut off and the steam passed through. The gas produced in this manner has a heating value of about 290 to 300 B.t.u. per foot. The intermittent character of this process renders it extremely flexible and blue water gas is therefore well adapted to providing for peak load demands of a gas service.

Carburetted water gas is simply blue gas with the addition of gasified oil, which raises the heating value of the blue gas from 290 to whatever point may be desired, depending upon the amount of oil added. This process has the same flexibility of output as blue gas, but is more costly.

Producer gas is the result of the incomplete combustion of hard fuel, such as coal or coke, and is made by passing steam and a limited amount of air through the burning fuel bed. The gas has a low-heating value, about 135 B.t.u. per foot and has a limited field of application.

The above gases are frequently mixed in a city supply system. The association of coal gas and water gas plants offer certain economies. The Peoples' Gas and Coke Company of Chicago, Illinois, for example, uses coal gas to supply the base load of the city mains, and uses the water gas generators to supply peak load needs. Some producer gas is manufactured and mixed with these gases to regulate the B.t.u. content. This arrangement permits the recovery of by-products from the coal gas retort, uses the resulting coke in the water gas generators, and permits a flexibleness of operation to accommodate the daily fluctuations in the gas load.

The problem of the gas industry in the immediate future is one of what kind or kinds of gas it will be most economical to manufacture. Gas, although its superiority as a heating agent is recognized, must nevertheless compete with solid fuels or oil. Hence economy of manufacture is an important factor in the future expansion of the gas industry. Mr. H. C. Porter,[3] after careful consideration of statistics including market and price trends, comes to the general conclusion that coal gas, particularly coke oven gas, will gradually replace other kinds of gas as the base load gas of the future. Mr. J. A. Perry[4] suggests the use of coal gas

[3] Porter, H. C., Probable Adjustments in Gas Manufacturing Processes to Meet the Needs of the Future, Proc. Amer. Gas Association (1925), 49–60.

[4] Perry, J. A., Types of Plants and Quality of Gas Best Suited for the Development of the Gas Industry, Proc. American Gas Association (1925), 814–24.

as a base load supplemented with lightly carburetted blue gas in meeting peak load needs.

One of the principal difficulties of the gas industry is the excess in winter consumption over summer, especially where the domestic load is an important item. This necessitates the erection of a plant large enough to take care of peak loads for a few days of severely cold weather with consequent idle capacity of a portion of the plant for a considerable period of the year. The overhead involved has been a serious factor in the cost of gas production. The gas industry affords an excellent illustration of an industry which must seek its proper economic position in industry through an integration of several allied industries. The association of coal gas and water gas plants, and the attendant economics, has been noted. Further study must be made to solve the problem of turning the excess summer capacity of the plant into productive use. Refrigeration and house cooling have been suggested as one possibility.

The manufacture of coke and gas and the associated by-products represent industries in which coal is the principal raw material for an imposing array of useful commodities. In the aggregate these industries require about 17 per cent of the coal production. The bulk of the coal is still burned in its raw state, or subjected to simple preparatory operations such as grading, sampling, and pulverizing. The most important customers of the coal industry are the railroads who take 27 per cent of the output. Almost any kind of coal of high heat value has been used by railroads except where city ordinances have specified a low volatile or smokeless coal. Other important outlets of coal are public utilities, vessels, and general industrial and domestic uses.

Coal for Power Uses.—The principal uses of coke and gas are to meet the heat requirements of industry. For the production of power, coal is burned largely in the raw state with little or no preparation. The largest single group of consumers are the railroads. These used, in 1928, roughly 120 million tons of coal of which 80 million originated on the lines of the consuming railroad and therefore paid no freight. In 1917, these same roads purchased 150 million tons, or more than 20 per cent in excess of the 1928 purchases. This decline is partly due to an increase in the use of fuel oil but the principal cause has been better fuel economy. The progress in efficiency is shown by the fact that the average consumption of freight locomotives per one thousand gross-ton miles has declined from 176 pounds in 1917 to 124 pounds in 1929.

Another large group of users are the electric utility plants. Of the nearly 100 billion kilowatt-hours of electricity produced by them, 60 per cent is produced by steam stations and the remainder by water power. Fuel oil and natural gas share with coal in the fuel needs of central stations. In 1929, 45 million tons of coal were used and 7½ million tons of coal equivalent in the form of oil and gas. The Mid-continent area and California, in particular, are witnessing a rapid expansion of gas as a public utility fuel. A decline in coal consumption is not expected, however, since the growth of the electric power industry will more than offset the gains made by the fuel and hydraulic competitors of coal.

The advances in the electric utilities are naturally reflected in the trend of the general manufacturing industries which have been shutting down their isolated plants and purchasing more and more of their power from central stations. Even the plants which have continued to generate their own power have frequently shown improvements in fuel efficiency. From 1909 to 1926, the physical volume of manufactured goods increased 74 per cent but the consumption of coal increased only 29 per cent. In fact, since 1919, the aggregate consumption in manufacturing has shown virtually no increases, although meanwhile the physical volume of the product has risen nearly 30 per cent.

Domestic Fuel.—The consumption of coal for heating houses is increasing. Not only is population growing but the higher standard of living manifests itself in better house heating for which more fuel is required. Most of the increase in the domestic heating load has gone to bituminous rather than to anthracite. The larger buildings tend to use bituminous and the anthracite is used more and more in the heating of detached houses. The expansion of bituminous coal in this field is undoubtedly assisted by the increasing proportion of the total population living in apartment houses.

Some Developments in Coal Utilization.—The burning of coal in its raw, untreated state is accompanied by wastes and inefficiencies that, with existing knowledge, are avoidable, and will not be tolerated indefinitely. Fuel technology is discovering methods of treating and using coal which not only make possible a more effective use of the heating value of coal but also enlarge its usefulness through the many products obtainable from it. There are many methods of treating raw coal, each one of which serves a special function or yields a specially adapted product. These methods of treating coal are many and various but the underlying processes used by each may be grouped under

1. Pulverization.
2. High Temperature and Low Temperature Carbonization.
3. Liquefaction.

The essential purpose of treating coal in the manner indicated above is either to increase its effective value, or to obtain a group of coal products having a wide range of usefulness in industry.

Coal Pulverization.—The value of pulverized coal is to be found in certain types of industrial heat applications and in the economies that can be effected by the mechanical advantages of handling coal in pulverized form.

The cement and metallurgical industries have established the value of pulverized, high volatile coals for their respective industries. Both require long flame combustion and both contend successfully with the coal ash by absorbing that part which settles into the clinker or slag.

The use of pulverized coal under boilers is the subject of considerable study and experimentation. Coal in pulverized form appears to offer certain advantages in handling and transportation accompanied by savings of labor. Moreover, some of the low-rank coals not suitable for use in lump form can, if pulverized, be made useful for steam generation or smelting. The effect of this is to enhance the usefulness of low-rank coals with every new and successful application of pulverized coal. One consequence of this is to release industry from the limitations of location near-by select coal fields. The smelting industry, and probably the gas industry, could profit by the larger ranges of coal available for their use.

A unique property of pulverized fuel is its mobility at high temperatures. The heating of pulverized bituminous coal throws off vapors and gases which surround the coal particle with a film which gives it great mobility. In this condition it resembles liquid and obeys the common law of liquids. This property can be made to enlarge the field of usefulness of pulverized coal. For example, heat operations hitherto performed by gas or oil can be accomplished by coal. Firing of boilers can be done with greater thermal efficiency and less trouble in clinkering ash.

The economic significance of the use of pulverized fuel rests in the fact that a fuel can be prepared which is more closely adapted to the particular needs of an industry and at the same time permits the utilization of lower-rank coals.

Pulverized coal, which has been carbonized, is convertible into lumps which burn smokelessly, leave no clinker, and have the characteristics of anthracite. In this form it becomes a potential competitor among the domestic fuels.

Carbonization.—The carbonization of coal has as its objective the manufacture of a number of coal products of a varied range of usefulness. Carbonization of coal may be defined as heating coal in the absence of air and driving out the volatile gaseous and liquid constituents, and leaving a solid carbon residue. The terms "high temperature" and "low temperature" carbonization are used to describe different variations of the process. In the former the coal is carbonized at a temperature of about 900° to 1200° C. The objective in this process is metallurgical coke and has been described previously.

Low temperature of coal may be defined as the heat treatment of coal in the absence of air at temperatures of 450° to 700° C. The aim of low temperature carbonization is to prevent the decomposition of the coal tars and thus obtain the maximum of liquid products and at the same time obtain a solid smokeless fuel. The solid residue obtained in this process is a semi-coke containing some volatile matter. It is unsuitable for metallurgical coke but can be used for the manufacture of easily pulverized, highly combustible material for pulverized fuel furnaces, or for the production of smokeless domestic fuel. This process also yields from two to three times as much tar as the high temperature carbonization. The principal outlets of coal tar are for the manufacture of roofing materials, wood preservatives, road surfacing, binding material for carbon manufacture, foundry cover and facings, besides small quantities used in the manufacture of dyes, drugs, and disinfectants. Tar can be cracked into lighter motor oils [5] or find an outlet in the liquefaction of coal by hydrogenation in the Bergius process.[6] Its value in either of these processes is conditioned largely by the supply and value of crude petroleum with which it would be a competitor.

Other products of low temperature carbonization are gas, some light oils, and ammonia. The yield of ammonia is considerably less than in the high-temperature process.[7]

The commercial success of the process depends upon its ability to make and sell a smokeless domestic fuel or a pulverized industrial fuel in competition with anthracite; metallurgical coke, briquets or fuel oil substitutes. Thus far it has not made an appreciable contribution to the domestic fuel supply. It received much attention as a possible source of light motor oils in the event that petroleum supplies were exhausted but it now appears that the production of oils from coal either by synthesis [8] or by hydrogenation [9] are better adapted to meet the need.[10]

[5] Egloff, G., The Cracking of Low Temperature Tars by the Dobbs Process, Trans., Int. Bit. Coal, Conf., 1926, pp. 788–799.

[6] Bergius, F., The Transformation of Coal into Oils by Hydrogenation, Proc. Int. Conf. Bit. Coal, 1926, pp. 102–127.

[7] The economic position of coal carbonization and by-product recovery is also discussed in Chemical and Metallurgical Engineering: Knapp and McMichael, Will It Pay to Process Coal for Generating Power? and McBride, R. S., An Economic Test of Low Temperature Coking, both in Vol. 36, No. 5, May, 1929.

[8] Fischer, F., *Ibid.*

[9] Bergius, F., *Ibid.*

[10] For a thorough discussion of low-temperature carbonization, the reader is referred to Fieldner, A. C., Low Temperature Carbonization of Coal, Technical Paper 396, U. S. Bureau of Mines, 1928.

The conversion of coal into liquid fuels is attracting attention, especially in Europe, since the publication of the experimental work of Fischer, Bergius, Patart,[11] and others. European interest in these processes arises from the absence of petroleum in the industrial nations of western Europe and a desire for national independence in the production of this important commodity.

The production of liquid fuels from coal, however, is still in an experimental state or in the early stages of development. Progress in this field has proceeded along two lines, both of European origin. The one proposed the complete gasification of coal and conversion of the gases into liquid hydrocarbons by synthesis, of which the process of Fischer and Patart are outstanding examples. The other method proposes to convert the solid substance into liquids by introducing hydrogen into the coal under high pressures and temperatures. The addition of hydrogen to the coal, under suitable conditions brings about a molecular rearrangement which results in the formation of liquid hydrocarbons from the solid carbonaceous material of the raw coal.

The value of the hydrogenation process lies in the fact that it enlarges the industrial usefulness of coal to include the functions now served by petroleum. The extent to which coal will rival the latter as a source of liquid fuels depends upon the cost of production of refined oils from each of these two raw materials. Undoubtedly, the advantage in the United States lies with petroleum. In Germany the process has entered the commercial stage and production is increasing.

The duration of petroleum reserves is uncertain, and also, the rate of discovery of fresh supplies may lag behind demand. In either event, the process of coal treatment can then supplement oil in meeting market demands.

[11] Patart, Gen. Geo., The Industrial Transformation of Bituminous Coal into Organic Technical Products, Proc. of International Conf. on Bituminous Coal, 1926, pp. 132–160.

CHAPTER VIII

PROBLEMS OF THE COAL INDUSTRY

THE chaotic and troubled history of coal in this country since the close of the World War has made of this industry an object of national interest and of political concern. Coal is suffering from the ills of maladjustment to the economic changes that have occurred in the post-war period. Coal mines are idle and miners are out of work. The balance sheet of the industry is in the red.

> For five years, at least, the industry has stood prepared, by actual demonstration, to supply two tons of coal for every one the consumer normally requires. During that period, with large numbers of mines either shut down from lack of orders or idle from other causes, it has not only met a high level of usual demand; in addition, on two occasions, it has also supplied, concurrently for months, large deficits caused by the strikes of the anthracite miners at home and of the British miners in markets abroad. . . .
>
> Throughout these five years, the price level of the industry has been continuously falling. To-day it rests approximately on the basis of twelve years ago. During the current season [1928], the consumers of bituminous coal will pay possibly a billion dollars less for their annual supply at the mines than they paid in 1920. At least one half of these huge savings has gone to increase the net income of more favored industries, the railroads and the power utilities, over whose own revenue rates the public stands guard. Indeed, the prices now realized by the producer are so low that the annual loss to the industry is estimated at sums reaching far into nine figures.
>
> What, then, is the trouble with coal?
>
> I doubt if any other question about industry can be put in this country to which the reply will come back so readily, so tersely, so unvaryingly. Issuing alike from legislative halls, public platforms, editorial rooms, and the chummy conclaves of Pullman smokers, reiteration has made the verdict unanimous. The diagnosis has already been adopted by acclamation: "Too many mines and too many miners!"
>
> Each doctor to the dilemma, of course, states the case according to his own therapeutics. "Too many sidings and too many coal cars," complain the railroads. "Too many coals and too many salesmen," growls the buyer. "Too many wage cuts and too many idle days," pleads the miner. "Too many expenses and too many price cutters," moans the management. "Too many competitors and too many losses," states the investor. "Too many risks and too many failures," decides the banker. "Too many strikes and too many alibis," says the public.
>
> In brief, everything about coal is too much or too many. Nevertheless, beneath

this apparent conflict of opinion lies an essential unity. It is excess. And the root of all the evils is the excessive capacity for coal production. [1]

The existing excess capacity in the coal industry arises from a number of causal events which have their origin in the two decades preceding the World War. For 20 years, from 1899 to 1919, the production of bituminous coal grew at the average rate of 18,800,000 tons a year.[2] Since then it has shown no increase. In the meantime production facilities were rapidly expanding under the influence of high prices of fuel in 1918, 1920, and 1923. The combined effect of arrested demand and increasing mine capacity, as illustrated by Figure 3, forced a closing of over 2300 mines and a reduction in number of 110,000 miners employed. In spite of this reduction, the disparity between mine production and capacity is still greater than before the war and further readjustment is inevitable.

The excess capacity finds its origin in the pre-war labor conditions and policies coupled with the factor of car shortage in times of peak demand. Prior to 1916, the most important factor in overdevelopment were the periodic strikes occurring in the unionized fields. The most important and regular were those in the Central Competitive Field beginning April 1st every other year.

In order to understand the effect of these strikes upon excess mine development it is necessary to analyze the competitive relationship between union and non-union fields. Coal is mined in 26 states and nearly 100 districts. Although the coal among these districts varies in quality and value, and a coal from a particular field or district cannot be made to serve all uses, nevertheless there is sufficient substitution virtually to make all coal fields competitive. With plenty of coal mines available, competition was exceedingly keen and overproduction resulted. In order to stay in business one district would cut wages which in turn would provoke wage reductions in competing districts. This process brought no more business to the coal industry as a whole and reduced wages below the point of subsistence.

It was out of this bitter and futile experience of low profits, low wages, and strikes that the present system of collective bargaining through wage agreements signed by miners and operators of four states was born. Representatives from Ohio, Indiana, Illinois, and western Pennsylvania—the "Central Competitive Field"—signed an agreement establishing a uniform day rate, an eight-hour day, and standard tonnage rates with local differentials, over the entire field. This agreement, signed in 1898, came, like the earlier Columbus agreement, of 1886, on a wave of prosperity that

[1] Anderson, George J., How Much Coal is Enough? Atlantic Monthly, vol. 142, December, 1928, pp. 823–33.

[2] Day, E. E., Coal in 1923, U. S. Bureau of Mines, pp. 519–520.

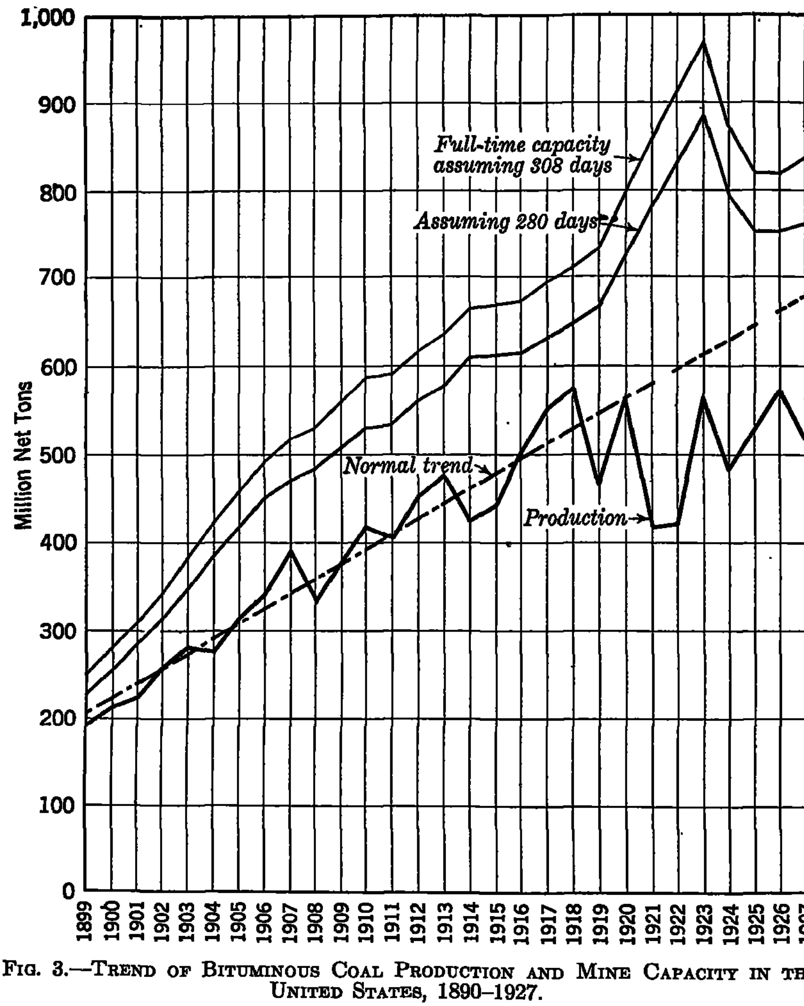

FIG. 3.—TREND OF BITUMINOUS COAL PRODUCTION AND MINE CAPACITY IN THE UNITED STATES, 1890–1927.

For the 20 years from 1899 to 1919, according to studies of Prof. E. E. Day for the Harvard Economic Service, the production of bituminous coal grew at the average rate of 16,800,000 tons a year. *Since then it has shown little or no increase.* In the diagram Day's line of "normal trend" for the period up to 1919 is projected through the postwar period to bring out the striking change in the line of actual production. Had the former rate of growth continued, the production in 1927 would have been 160,000,000 tons greater than it actually was. At the same time that the former growth of demand was checked the capacity increased sharply and by 1923 the excess of capacity over production was so marked that readjustment became inevitable:

followed a period of depression. But whereas the earlier attempt had broken down as one district after another withdrew or as individual operators refused to maintain the scale, the agreement of 1898 was enforced, partly through the general realization on both sides that the conditions existing before were intolerable; partly, be it said, because the inclusion of the check-off in the district contracts so strengthened the union that it could enforce the agreement.[3]

Removal of the severe competitive conditions among districts of the Central Competitive Field, brought about by the conclusion of a general wage agreement, merely shifted the struggle to another quarter—the non-union territory comprising the Virginias, eastern Kentucky, Alabama, and some of the fields in the western States. Although these fields lie farther from the centers of consumption than do the union fields the disadvantages are largely offset by the fact that they possess better quality coal and enjoy lower ton-mile freight rates. The scale of wages in the non-union field is generally lower.[4] This factor, together with other contributory ones, promoted a rapid development of coal mining in non-union territory growing with every strike in the union fields. Eventually capacity expanded to such a degree that non-union fields were in a position to supply the country's coal needs without the aid of union mines. This was the case during the strike in certain parts of the Central Competitive Field from April 1, 1927, to October 1 of that year.

The recurring strikes that have visited the union fields have not always been a detriment to operators and miners. Strikes were usually preceded by a dull market, large supplies of coal, and intermittent work at the mines. The effect of suspension of operations was eventually accompanied by high prices and active demand with the result that operators could afford to meet union demands and still profit from the higher prices occasioned by the previous cessation of production.

Since the World War there have been two national strikes of the union miners so widespread as to cause an acute shortage of coal. These strikes, occurring in 1919 and 1922, had a marked effect on increasing productive capacity in the non-union mines. These had expanded to such an extent that, during the strike of 1927, the non-union fields were able practically to meet the demands of coal consumers.

Apart from interruptions in production of coal as an element in increasing capacity is the factor of railroad transportation of coal. The output of the mines becomes available no faster than it can be trans-

[3] Tryon, F. G., The Effect of Competitive Conditions on Labor Relations in Coal Mining, Annals, January, 1924, p. 84.

[4] It should be noted that about 70 to 80 per cent of the cost of bituminous coal may be set down to labor costs.

ported to the consumer. In times of peak demand the railroads have not always been able to transport as much coal per week as the country demanded or the mines could produce. At such times "car shortage" has been the immediate cause of inadequate supplies.

The acute shortage ensuing from the combined causes of strikes and inadequate railroad service resulted in periods of high prices, especially in 1920 and 1922, and these in turn have been potent causes of the development of productive capacity in excess of requirements.

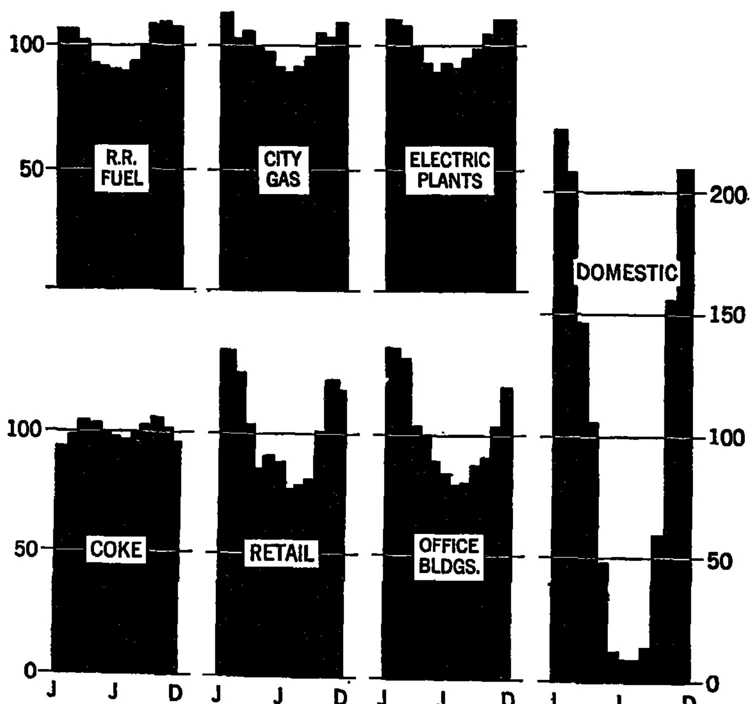

FIG. 4.—SEASONAL VARIATIONS IN THE CONSUMPTION OF BITUMINOUS COAL BY SEVEN CLASSES OF CONSUMERS.

The daily rate for each month is represented as an index number, the average for the year being taken as 100.

The fact of irregular demand due to seasonal consumption also has been an incentive toward excessive development of soft-coal mines. Previous to the war the cost of opening a soft coal mine was small. Coal lands were cheap, and little machinery was required. The good market in fall and winter offered profits. The character of this seasonal demand is shown in Fig. 4. The railroads use more fuel in winter than in summer, partly because of differences in the volume of traffic but chiefly because of larger unit consumption in cold weather. Much the same type of curve is shown by the city gas plants and electric central stations. Even the consumption by general manufacturing industries is greater in winter than in summer because of the large amount of fuel required to heat factory buildings. The extreme of seasonal fluctuation is shown by the domestic consumption.

Other Factors Affecting Excess Capacity.—Mechanization and continuous operation of the mines are potent factors in increasing mine capacity. The obvious effect of the use of cutting machines and the introduction of mechanical loaders is to hasten the rate at which coal can be removed from the face of the seam. Hence, without opening new mines, but merely by displacing hand-mining methods by machines in existing mines will have the effect of enlarging the productive capacity. Add to this the possibility of continuous operation of a mine, that is the introduction of two or three working shifts per day, and the effects on excess capacity will be significant indeed. Hamilton and Wright calculate this excess capacity to have a productive power of 2.5 billion tons of coal five times the nation's annual requirements.[5]

The condition of excess capacity, previously noted, is aggravated by the fact that the rapid increase in coal demand so conspicuous in the period before the World War has been checked. See Fig. 3. Responsible for this condition are the factors of substitute sources of power and increases in fuel efficiency. While the consumption of bituminous coal in 1927 was actually 6 per cent less than in 1917 the production of oil was 169 per cent greater, that of natural gas 82 per cent greater, and that of water power 110 per cent greater. The total supply of raw materials of energy shows an increase of 18 per cent for the ten-year period but the increase has come from sources other than coal.[6]

However, not all of this increase in other sources of power represents displacement of coal. Water power replaces coal only in regions where it is a competitive source of electrical energy. Natural gas is used largely in non-competitive markets. Fuel oil, however, has displaced coal in many instances, and, as long as it continues to come on the market abundantly and cheaply, it will make serious inroads on the coal market. However, developments in the oil industry indicate an increasing tendency toward cracking fuel oil into gasoline instead of burning it under boilers.

The unequal growth of the several forms of power has brought about a remarkable shift in the sources of the country's energy supply. In 1913 bituminous coal furnished 72.7 per cent of the total energy derived

[5] Hamilton, W., and Wright, H., The Case of Bituminous Coal, 1925, p. 168.

[6] Tryon, F. G., et al., Coal in 1927, Table 3, p. 342.

from fuels; in 1928 its share had fallen to 57.7 per cent. The percentage of the grand total derived from coal, oil, gas, and water power was as follows: [7]

	Anthracite	Bituminous	Oil and Gas	Total Mineral Fuels	Water Power
1913.........	14.4	72.7	12.9	100.0	3.0
1928.........	9.0	57.7	33.3	100.0	8.5

Advances in Fuel Efficiency.—Of equal importance in slowing down the growth of the demand for coal is the great improvement in the efficiency of fuel utilization. The greatest strides in coal economy are shown in the electric power utilities. The public utility industry has shown a remarkable growth in the last 25 years, increasing from 4 billion kilowatt-hours in 1902 to about 97 billion kilowatt-hours in 1929, of which 63 billion kilowatt-hours was derived from coal. In the meantime the consumption of coal increased from 11 million tons to 44 million. The small ratio of increase of coal consumption as compared with the increase in electrical energy output is explained when one notes that the consumption of coal per kilowatt-hour of electricity produced dropped from 6.6 pounds in 1902 to an average of 1.69 in 1929. This is graphically shown in Figure 5.[8]

In the field of transportation, similar economies in fuel utilization are observed. Although the physical volume of railroad transportation has grown rapidly, advances in fuel economy together with the growth in fuel-oil consumption has brought about an actual decline in total consumption of bituminous coal since 1918. Although the railroads did 9 per cent more work in 1927 than in 1917, they required 13 per cent less coal.

A similar condition is shown by the iron and steel industry, which absorbs directly or indirectly 16 per cent of the total supply of bituminous coal. The volume of the product is increasing, but advances in fuel economy have caused an actual reduction in the total consumption of coal. In 1904 the ratio of tonnage of coal used to tonnage of iron and steel produced was 2.01; in 1927 it had dropped to 1.4. The largest element in this saving has undoubtedly been the substitution of by-product for beehive coke. Other factors in the reduction in fuel consumption per unit of pig iron and ingot steel are the growing use of

[7] Tryon, F. G., et al., Weekly Coal Report, U. S. Bureau of Mines, November 16, 1929.

[8] Coal in 1927, U. S. Bureau of Mines, p. 419.

scrap in the open-hearth furnace, the rise of electric steel, and the tendency to purchase power from public utilities.

The coal industry, in spite of exhaustive investigations, recom-

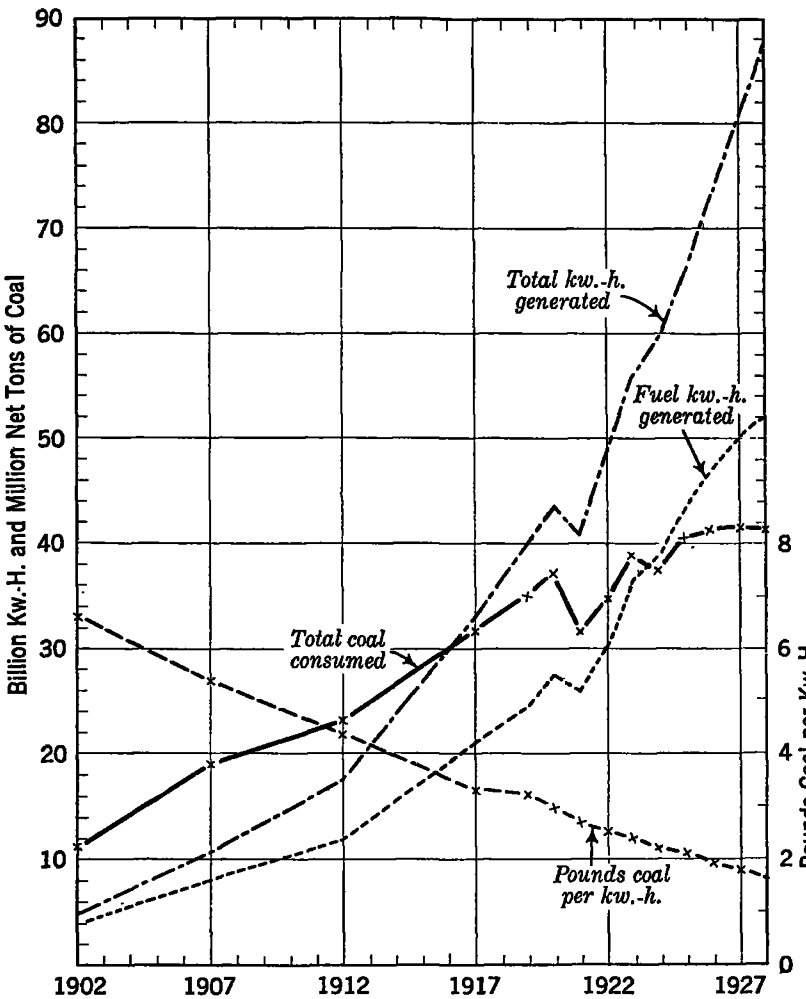

FIG. 5.—TRENDS IN CONSUMPTION OF FUELS BY ELECTRIC POWER PLANTS (PUBLIC UTILITIES) IN THE UNITED STATES, 1902–1928.

mendations, etc., remains in a chaotic condition. In a symposium [9] conducted by *Coal Age* and published early in 1929, the suggestions

[9] How Can We Make the Coal Industry More Profitable in 1929?, *Coal Age*, January, 1929, pp. 6, 24, 44.

made by persons engaged in coal production for the most part were impossible of fulfillment or were a recognition of the helplessness of the industry to get out of the morass. In the meantime the years 1928 and 1929 showed declining consumption, a fact which "increased sales realization" or "better merchandising" cannot overlook. To return profits to an industry by increasing sales means that more coal must be purchased by consumers. Statistics of consumption do not give promise that this will be realized.

Suggestions for the rehabilitation of the coal industry are as varied in number as the sources from which they come. They may, however, be grouped into two general categories, as follows:

1. Improvement within the industry itself, through better sales methods, better management, cooperative association, consolidations accompanied by closing of high-cost mines and curtailment of production.
2. Regulation by the Federal Government, as for example, through the I. C. C. or a specially created Coal Commission.

Since the U. S. Coal Commission was the first attempt at a comprehensive study of the coal since the conditions in this industry became acute, its studies and recommendations will be considered first.

The Commission was created by act of Congress approved September 22, 1922, and expired September 22 of the following year. The record of its studies are embodied in a lengthy report of four volumes and an atlas of statistical tables with some unpublished documents in the custody of the Director of the U. S. Geological Survey. The studies of the Commission were concerned with living conditions of the miners, returns to owners and operators, the question of coal supply and shortage, the price of coal, and the extent of the coal reserves.

In its final recommendations for the rehabilitation of the coal industry, the Coal Commission proposed the creation of a coal division of the Interstate Commerce Commission with power to gather and publish information on the quality of coal entering interstate commerce; costs and profits of the coal business of operators, wholesalers, and retail dealers; and earning, living conditions, and living costs of the miners. The present activities of the U. S. Geological Survey gathering facts on coal resources and production, and of the Bureau of Mines pursuing investigations in mining technology, mining safety, and fuel economy, would be continued. The special coal division of the Interstate Commerce Commission would undertake the collection of information about finance, operating costs, etc. The changing character of the facts from season to season and among mines and districts necessitates a permanent fact-finding body continuously engaged in the task of gathering facts about the current conditions of the coal industry.

In times of prolonged suspension of mining the Interstate Commerce Commission would be empowered to act as fuel distributor to insure an equitable and efficient distribution of coal, a function which the State and Federal Fuel Administration attempted during the emergency of the World War.

Federal control of the bituminous coal industry is recommended for the specific purposes of preventing over-development of the industry, for more economical transportation of coal, and for insuring a continued and uninterrupted flow of coal to consumers in times of shortage and peak demand. Recognizing the fact that shortages, when they occur, are often due to an inadequate car supply, the Commission's recommendations invoked the Federal Power over interstate commerce by revising freight rates on long and short hauls to discourage the transportation of coal over undue distances, when near-by coal of similar quality can be obtained. Furthermore, the problem of the most efficient utilization of the carrying capacity of the railroads could be accomplished by allotting cars to mines whose ability to market its coal had been demonstrated. For this purpose the Commission recommended that "the rating of a mine for purpose of car distribution, consideration should be given to the commercial ability of the mine to sell its production as well as its physical capacity to produce." This recommendation is intended to prevent the diversion of coal cars from well-developed and normally functioning mines to high-cost snow-bird mines, but rather to concentrate the car supply where it can be used to best advantage.

A practical way of controlling the distribution of coal cars to mines and markets would appear to be the licensing of operators, wholesalers, and jobbers who desire to ship coal from one state to another, or who wish to buy and sell in interstate commerce.

The consolidation of mining companies and properties in the interest of more efficient and economical mining operations is approved. This would necessitate the removal of legal barriers against monopoly and governmental supervision to prevent the evils of monopoly once current in the anthracite industry. This, however, for the present is no more than a pious hope.

Seven years have passed since the Coal Commission completed its work and rendered its report. Beyond authorizing the printing of the report, Congress has taken no action on the recommendations or enacted measures of a constructive nature. The ills of the coal industry remain substantially as they were in 1922 and 1923. Moreover, the recommendations of the Commission, if enacted into law, would still leave untouched the basic element of the industry—excess capacity. The regulatory measures that could be effected through the Interstate Commerce Commission would be in the nature of promoting a more effective use of the transportation system in keeping the consumer supplied with coal. The question of dealing with excess mine capacity was beyond the power of the Commission. The formulation of recommendations for the compulsory closing of mines would have involved the infringement of property rights which could not be sustained by legislation. Nevertheless, if the coal industry is to seek a way out of its dilemma, the initial step must be the closing of unneeded mines.

An attempt to reconstruct the coal industry through self-help was attempted by a plan formulated by the Consolidation Coal Company as described by G. J. Anderson, vice-president of the company. In view of the fact that the plan was undertaken by one of the largest producers of bituminous coal, it is worth while describing here. In a review of the coal industry, Mr. Anderson points out the dangers and pitfalls of federal regulation, even if the administration officers charged with the duty of salvaging the coal industry were clothed with dictatorial powers. In a summary of the problem, he says:

> Let us sum up. The present problem of coal is basically one of flood control. The huge excess of productive capacity, due partly to expansion for wartime needs, to over-investment, to the substitution of oil, natural gas, and water power, to increased efficiency of combustion, and due partly also to chronic causes, such as transportation factors, labor strikes, and the practices of the buyer, willful or otherwise, holds more mines in operation than can profitably be sustained; retains more men than can be fully employed; pours forth more coal than can be adequately sold. This entails not merely a deficiency in the income to be shared by all parties. The price level, thus depressed, results in an actual deficit for the industry as a whole.
>
> Anyone may be pardoned his inability to see clearly how a hasty levee of political sand bags will restrain this economic flood.
>
> Such is the situation with which hundreds of my fellow coal producers are now struggling. I seek to present no brief in their behalf, for I see their faults and their failures even more clearly because I share them. But I would have them seen by others, as I view them, with sympathy rather than with blame. We are in the grip of a severe and relentless malady, and we must fight our way back to economic health without the quick and easy remedies of dictatorship.
>
> I believe the industry must look largely to self-help. It is my own opinion that the keys to the quickest, though not to the most complete, relief are in its own hands—closer cooperation between districts, mergers of existing properties, a new attitude of mind. Better means of cooperation may involve a long process of education in an enterprise noted, even notorious, for its individualism. Mergers, especially in the ownerships of natural resources, require difficult appraisals and prolonged negotiation.

But for a new attitude of mind all a normal man should need is a few frank hours with himself.[11]

In pursuance of this thought, the following declaration was formulated, approved, and announced to our fellow coal producers:

"The Consolidation Coal Company believes that the present plight of the bituminous coal industry will not be remedied by forcing unwanted coal upon an unwilling market. It sees no relief, either to the industry or to any producing company, by cutting prices to a level that permits a mine to remain in production with its natural overhead unabsorbed in its average realization.

"The Consolidation Coal Company believes that no present useful purpose nor any contribution to future stability is to be gained by further cutting wages below a sound economic level. Whatever may be the temporary relation of labor costs to selling prices, it holds that the primary object of both mine labor and mine management must be the most regular work-time possible under a proper wage base.

"Holding, as it does, these beliefs, the Company is attempting to bring both its marketing and operating policies into line with what it conceives to be a constructive economic basis. To that end it is closing for an indefinite period some of the least efficient mines, and consequently must dispense with the services of a considerable number of valued and loyal employees.

"The Company is confident that the elimination of these mines will not only be to the advantage of the industry at this time, but that the greater concentration, thus enforced, will yield benefits to the labor remaining and to the Company as a whole.

"On the other hand, it is recognized equally that there would be a loss to the industry if many of the experienced employees, thus displaced through no fault of their own or by any dissatisfaction with their services, were unable to continue in bituminous coal.

"The Company has, therefore, taken this opportunity to give to its fellow producers a frank statement of the policy thus adopted. Further, in behalf of any former employees seeking affiliation elsewhere in the industry, it wishes earnestly to bespeak all proper consideration and courtesy for their applications arising out of this action.

"If the industry is to progress rapidly toward its rightful economic recovery, the Consolidation Coal Company believes each and every producing unit must make some sacrifice to that end. We speak only for ourselves and only in the spirit of friendly cooperation. The retention of the most economic mines, and the present elimination of the least efficient, adopted voluntarily as a general programme, seems to offer the speediest and most effective relief for all."

In embarking upon such a policy, the promoters were well aware of the fact that its success was contingent upon similar action by other bituminous coal operators. Notwithstanding this effort, in the bitter competitive struggle, the industry continued to sink to lower standards of living for labor and to lower standards of business for capital; seeking to solve excess capacity by more and more output, deficient income by less and less revenue; trying to repair damaged profits by larger patches

[11] Anderson, G. J., How Much Coal is Enough? *Atlantic Monthly*, December, 1928, p. 830.

of loss. Competitors made several wage reductions and wage scales alleged to be paid in that district declined 15 to 25 per cent below the scale established by the Consolidation Company and adhered to since 1928. Standards disintegrated in the territory, with many companies defaulting from a month to three months in wages, while some companies were forced into bankruptcy.

Accordingly, it occasioned no surprise in coal circles when, after a two-year attempt to stabilize the industry, the company announced an abandonment of its policy.

A constructive economic policy in regard to the coal industry can be inaugurated only after the rocky road of deflation of productive capacity has been traveled and the industry is released from the grip of ruthless competition among producers without regard to profits. Curtailment of capacity to meet consumption, however, will fall short of the needed readjustments to insure a healthy economic state of coal. Without the need of drastic programs of government regulation, or abandoning the competitive system of production, the coal industry should and can be properly safeguarded against the recurrence of the evils that have beset the industry for nearly a decade. The approach to a state of security lies in consolidation and in transportation control. In 1927 there were about 7000 mines in operation. Size of individual companies varied from a few with an output of over 500,000 tons annually to several thousand companies with a small output of about 10,000 to 20,000 annually. One of the largest of the companies, e.g., the Consolidation Coal Company, operating mines in West Virginia, supplied 3 per cent of the year's production. Under such conditions, no single company is in a strong enough position financially to weather a long and severe period of unbridled competition or the exigencies of car-shortage occurrences. A merging or consolidation of several producers, preferably within a field or district, or within a normal marketing zone, would effect economics in the use of the transportation equipment. Moreover, inasmuch as consolidation must be accompanied by elimination of some of the mines, the natural procedure is to effect the closing of high cost mines, or maintaining them for peak demand periods only. Consolidation of mining properties into larger units enables the management to take advantage of the economics of large scale operation, mechanization, better mine transportation equipment, engineering advice, safety practices, etc. Such an organization will be in a better position to serve the coal-using industries in a satisfactory manner. Consolidation, therefore, should be accompanied by regulating measures designed to protect the large coal organizations against irresponsible operators who come into the market only when prices are high and who make no pretense of maintaining an organization that is in a position to render continuous service. It is in this connection that the suggestion of the Coal Commission of licensing mines and rating them, for purposes of car distribution, according to their commercial ability to sell coal, rather than merely to produce, can be effectively applied.

The method of rating mines according to their productive capacity encouraged overdevelopment for, by dividing the cars according to the capacity to produce, these rules have put a premium on overdevelopment.

The proposed arrangement would afford an element of protection to coal companies performing year-round service against the unequal competition of unscrupulous competitors. The charge of favoritism and special privilege may be made against such a proposal but it is only necessary to point out that, with the thousands of mines available, consolidation would not run toward monopoly but rather toward fewer but larger competitive groups. The public has recourse to the powers of the Interstate Coal Commission for protection against possibly extortionate prices. The recommendation of the Commission for a coal division of the Interstate Commerce Commission with power to ascertain facts about the supply of coal stocks above ground, etc., and, in an emergency, power to act as coal distributor, is a powerful weapon against abuses or a panicky feeling among consumers thereby precipitating high prices. Finally, the management of a coal enterprise will be able to see that profitableness will follow good service.

Hence, the existing legal barriers to consolidation, grouping, or pooling of bituminous mining operations, should be removed, retaining only such legal supervision as is necessary to protect the public interest.

An approach to the economies available through consolidation will probably be made first through the sales end of the industry. The move of five independent companies in western Pennsylvania to consolidate their sales departments is a direct attempt to eliminate some of the economic wastes of coal distribution.[12] Consolidation of marketing departments can be accomplished with greater ease than in the production branch. The former does not involve a merging of the properties themselves with its attendant legal and financial problems. It also offers opportunity to study at first hand the normal market demands, the extent of an economical marketing area, and the particular needs of the various customer groups. The classification and preparation of coal for specific uses is possible under an enlarged marketing organization with better services to the consumers. The test of the practicalness of cooperative marketing efforts will be the ability to offer a better

[12] New York *Times*, March 30, 1930.

service to coal consumers and at the same time survive the fierce competition within the industry.

An improvement of competitive conditions within the industry also requires a permanent and satisfactory adjustment of the conflict over lake cargo and tidewater railroad freight rates. The controversy over freight rates between western Pennsylvania and eastern Ohio soft coal producers on the one side and southern operators on the other has been spread over eighteen years and involved an expenditure on the part of the Northerners estimated at nearly a million dollars. The western Pennsylvania and Ohio producers say that their natural and rightful advantage in being located comparatively close to the lake, for transshipment beyond Lake Erie points, has been virtually wiped out by railroad rates from the South that amount in some instances practically to hauling coal from that section hundreds of miles for nothing. The Southerners come back with the declaration that they are entitled to their chance at development and that otherwise Pennsylvania and Ohio might operate at dangerous monopoly.

The railroads of the respective districts have been drawn into the controversy by reducing rates on coal hauls in an effort to aid the mines whose coal was carried over their roads. The controversy has been passed on to the Interstate Commerce Commission which is trying to establish the moot point as to whether it has the same jurisdiction over minimum as well as maximum rates. Until a definite policy is laid down the question of rates will merely add to the turmoil within the coal industry.

Integration of coal-mining properties with large coal-consuming industries such as the railroads, public utilities, and the iron and steel industries, is becoming more prevalent. This plan of coal distribution removes a particular group of mines from the exigencies of competition and to that extent it delimits the problem. The large bulk of coal, however, is used by widely scattered industrial plants, homes, offices, and farms. For this group of purchasers, the independent marketing organizations are necessary and the problem of increasing the effectiveness of coal marketing must be worked out here.

The inauguration of a constructive economic policy for coal must needs be an evolutionary growth. The complexity of the industry precludes the possibility of success through government supervision with the elaborate bureaucratic organization necessary to administer it. The panacea of government control or nationalization is a snare and a delusion. Revolutionary measures in coal administration had better be avoided unless a method of working out the problem within the industry itself, aided by appropriate legislation, has shown itself to be a failure.

Other Problems of Coal.—The above discussion of coal has been concerned with a major problem, that of attempting the formulation of a coal policy and coal-producing organization that is in harmonious adaptation to the industrial civilization in which it plays its role. Another group of problems relates to the harmonious adjustment or integration of elements within the industry itself. Within this category lie the troublesome questions of relations between miners and operators, and the problems of coal mine management, engineering improvements, promotion of safety, and the responsibility of the coal industry to the welfare of mining communities.

Labor relations in the coal-mining industry received a thorough inspection by members of the Coal Commission and much information on the conditions under which the miner is employed and the conditions under which the operator employs was brought to light. Disputes between these two frequently antagonistic groups occupies a large place in the checkered history of coal. Nevertheless, the essential unity of interest of both groups in the prosperity of the industry should lead both operators and miners "to study the problem of unemployment and together seek to stabilize the industry; to study by joint committees the whole rate structure and its relations to the different jobs in the mines; and to perfect the machinery for settling disputes through conciliation or voluntary arbitration, with the adoption in the non-union fields of adequate checks on the exercise of the right to discharge. The operators could well pay more attention to the problem of labor adjustment. The success of many companies in establishing good relations warrants special attention to the training of foremen in management and to the centering of responsibility in labor relations. The operators also need more effective organization for labor relations, and the Commission recommends district and national labor commissioners, men of the highest type, who can work out a national labor policy."

The phase of the coal industry dealing with the living conditions of miners in the mining communities bears a closer relationship to the coal mine management than is the case in manufacturing or other industries. Frequently, these communities are isolated, located in difficult topographic and physiographic surroundings, offering difficulties toward the building of an attractive community. Actual conditions are very frequently far from inviting in their appearance and in the facilities of ordinary comfort, sanitation, and health. The coal company is frequently called upon to operate stores and furnish medical care.

The first responsibility of the operator, under these conditions, is to pay a wage which will permit the workers in his mine to erect homes and build a community compatible with a decent standard of living. The mining company may find it necessary to take the initiative in fostering improvements, if a community is not civic minded. Specifically, the employer himself may need to give attention toward providing schools, recreational facilities, food supplies. In the end, however, responsibility for improvement of these conditions should rest with the members of the community itself.

Coal Mine Management.—The essential contribution of the engineer toward more efficient and lower cost mining lies in the field of management. In its broader sense, management in the coal industry should include the elements of mine capacity, coal storage, and railway service. As long as excess mine capacity is permitted to continue, the efforts of the mine operator to establish efficiency of production in an individual mine may be of no avail. Existing methods of competition will still force prices below cost of production, however low that cost may be. Likewise, the failure to store coal with the consequent fluctuation in demand from month to month necessitates the maintenance of a large reserve mine capacity and of miners, both adding to the cost of production.

What is gained by management underground may be lost by the high cost of irregular demand on the other side of the tipple. In regard to the transportation, the proper distribution of coal cars to the mines is essential to continuous functioning of operations in the mine itself. The value of scientific management applied to underground operations is predicated upon the successful application of a constructive economic policy to the coal industry in its entirety.

In confining attention to underground work, the coal operator is compelled to recognize the fact that management is the controlling factor in profitable mine operation. The transition from hand to machine mining, the introduction of electric haulage, ventilation, and safety appliances necessitates a coordination of underground activities. Under the methods of hand mining, the management fell to the mine foreman. He is charged with a variety of duties such as assigning men to their working places, inspecting the coal that is being loaded, discussing the miners' problems and complaints, besides supervising the work of the company men engaged in timbering, track laying, trolley wire installation, excavating, etc. In addition to this the foremen in a mine direct the car traffic. The supply of mine cars is one of the most vital operations in coal mine management. The rate at which a miner can load coal, the continuity of his work while at the face of the mine, depends upon his having available and ready for use a supply of cars upon which to load his coal. With the introduction of machine mining and mechanical loading, accompanied by a more rapid output of coal, the factor of management takes on an added importance. The use of mechanical equipment in the mine, i.e., the coal cutter, the coal loader, and the mine cars must be coordinated in such a way as to provide uninterrupted service in removing coal from the face of the seam as fast as it is produced.

CHAPTER IX

COAL IN FOREIGN COUNTRIES [1]

COAL is found in greater or lesser quantities on every continent and in nearly all countries of the world. Production is recorded in 54 countries including dependencies and colonies. A description of the world's known resources of coal is a task beyond the scope of the present work. Moreover, a knowledge of the world's coal reserves is entirely too inadequate to make an estimate of reasonable accuracy. It is sufficient to say that, from the data available, North America is most abundantly supplied, with ample quantities in Asia (mostly in China) and Europe, while the remaining territories of the globe appear to have limited or scant reserves.

A rough measure of the relative importance of these several coal-producing countries can be obtained by examining the table of production given below.[2]

TABLE III

COAL PRODUCTION OF IMPORTANT COUNTRIES IN 1929 (IN MILLION NET TONS)

United States	608.9
United Kingdom	297.5
Germany	00010
Coal	180.0
* Lignite	192.4
France	60.5
Russia	44.0
Poland	37.6
Japan	36.9
Czechoslovakia	32.2
Belgium	29.6
British India	25.9
Canada	17.2
Australia	13.8
Union of South Africa	13.2
Netherlands	12.7

* Four and one-half tons of German lignite is considered the equivalent of one ton of hard coal.

[1] Redmayne, Sir Richard, Coal Resources of the World, Trans. World Power Conference, Vol. I, 1924, pp. 420–448.

[2] Statistische Übersicht über die Kohlenwirtschaft in Jahre, 1929, Reichskohlenrate, Berlin.

The outstanding fact presented by this table is the dominance of the United States, Germany, and England, with lesser, but nevertheless important contributions from France, Poland, Czechoslovakia, Belgium, and Russia. The second noteworthy fact is the concentration of coal production in those countries bordering the North Atlantic which, in the aggregate, account for three-fourths of the world's output. The other important producers are the nations of central and eastern Europe. Chief interest centers around the great coal industries of the British Isles and the Franco-German coal industry on the continent.

The Coal Industry of Western Europe.—Limitations of space preclude an extended discussion of that small but vastly important region of western Europe in which are located the coal, iron, steel, and associated industries upon which the industrial, political, and commercial strength of Europe is built. A region, scarcely equal to New Jersey in area, embraces parts of four nations—Germany, France, Belgium, and Luxemburg. Within the confines of this area are found the basic raw materials and fabricating plants from which flow iron and steel goods, machines, chemicals, etc., into the markets of the world. These industries support a dense population of miners, and commercial and industrial workers. It is the most densely populated and wealthiest area of Europe.

The basic element in the industrial structure of this district is the vast reserve of coal in the basin of the lower Rhine in Germany. Here are located six coal fields which have a total known reserve of 86 billion tons of coal, of which at least 40 per cent is suitable for coking, far more than is necessary to smelt the iron ore of all Europe.

About three-fourths of this coal is in the Westphalian field of Germany. This field is in the lower Rhine basin chiefly east of the river. The strategic importance of this field in the economic life of western Germany becomes evident when it is noted that, in addition to being near tidewater, an important factor in export trade, this Westphalian field is connected by railway, river, and canal to the centers of iron and steel manufacturing in Lorraine and Belgium. Limitations of coal supply in these two countries compel them to draw upon Westphalian coking coal for their metallurgical industries. Besides supplying the needs of its neighbors, this coal-producing field is also the scene of an extensive manufacture of iron and steel. The physical characteristics of the coal deposits permit the lowest cost of coking coal among the various coal fields.

West of the Westphalian field and beyond the Rhine lie two other coal fields, less extensive and more costly to mine. The southernmost of these fields, Aix-la-Chapelle, extends westward across Belgium into northern France, the Baisin du Nord. West of the Lower Rhine, near Cologne, there is also an extensive field of lignite. This product is not used in the metallurgical industry but is developed on a large scale for making briquets.

The Saar coal field, formerly a part of the German Empire, but now, for a time at least, controlled by France, lies adjacent to the Lorraine iron field. The coal of the Saar field is of an inferior grade for coking purposes. Small quantities of coke are manufactured, but in blast furnace practice it is usually mixed with Westphalian coke. The principal outlet of this coal field is in the non-metallurgical industries and for domestic uses.

For purposes of industrial classification the Germans divide their coal deposits into what are designated as stone coal and brown coal. The stone coal is comparable to the medium-rank bituminous coals of the United States and are made to serve essentially the same purposes. The significance of this class of coal in the metallurgical industries is evident from the fact that approximately 40 per cent of the output of the Westphalian syndicate is sold to the iron and steel plants.[3]

The Brown Coal Industry.—The brown coal industry in Germany is of some considerable interest because of its growing significance in industry. This coal is an earthy, pulverulent substance with a varying moisture content sometimes as high as 60 per cent. Although the tonnage output (192 million tons in 1929) exceeds that of the hard coals, its heating value is far less, being equated to the latter at a ratio of 2 to 9. A small quantity is made into briquets, but by far the greater amount is marketed as crude lignite. The low-heating value per ton precludes long shipments and about three-fourths of the output is marketed within 30 miles of the mines. A considerable quantity is used by the public utilities. The advent of the hydrogenation process, for which these brown coals are adapted, will tend to increase their economic importance.

Organization of the German Coal Industry.—The German coal industry is closely supervised by the government through the medium of three closely cooperating institutions, viz., (1) the regional syndicates, (2) the Imperial Coal Union, and (3) the Imperial Coal Council.

The regional syndicates are essentially producers' cartels who assign production quotas to their members and are responsible for the sale and distribution of fuel. These regional syndicates are associated in membership in the Imperial Coal Union. The functions of this body, among others, are to assign quotas to each of its members, define their market areas, and fix maximum prices. The Imperial Coal Council is

[3] Stockder, A. H., German Trade Association, The Coal Kartell, 1914, p. 17.

comprised of producers, industrial consumers, labor, dealers, and the government. Its function is to formulate policies for the operation and regulation of the industry along broad social and economic lines to promote the general welfare of the nation. It is a sort of governing body with powers to examine and regulate the basic arrangements made among the syndicates composing the Imperial Coal Union. The power exercised by the government is practically limited to its membership in the Council of which it has three out of a total of sixty.

The German coal industry may be regarded as a self-governing industry with the government exercising a veto power through the Minister of Industry.

The regulatory bodies, local and general, have wide powers and include such important phases of the industry as quotas of production and distribution. The arrangement, however, does not disturb private property in coal mines or profits to private operators, whether producers or dealers. While this plan did not, at its inception, meet with the approval of the socialistic groups, who wanted nationalization, the results so far seem to indicate a fairly workable plan. It has succeeded in effecting a degree of stabilization in the coal industry through planned production and regulated distribution. Its ultimate success as a social experiment can be determined only after a reasonable time has elapsed during which time the industry can prove itself.[4]

The British Coal Industry.—Great Britain is favored with large reserves of excellent quality, and strategically located with reference to manufacturing and trade. The most authoritative estimate of the coal resources of Great Britain are given in "The Coal Resources of the World" issued by the 12th International Geological Congress, 1913. This estimate places the known reserves of England and Wales at 120 billion tons and in Scotland at 20 billion. The coal beds are geographically distributed in such a manner as to make the fuel available to almost every section of the country without a long haul. The industries of the Scottish lowlands are supplied by near-by coal beds on the western coast. The industrial cities of Manchester, Sheffield, Leeds, etc., lie over the coal fields of north England, and the high-grade Welsh

[4] For a discussion of the continental coal and iron industry, the reader is referred to Greer, G.; The Ruhr-Lorraine Industrial Problem, 1925; Leith, C. K., The World Iron and Steel Situation in Its Bearing on the French Occupation of the Ruhr, Foreign Affairs, June 15, 1923; Brooks, A. H., and LaCroix, M. F., Iron and Associated Industries of Lorraine, the Saar District, Luxemburg, and Belgium, Bull. 703, U. S. A., 1920; Eckel, E. C., Coal, Iron and War, 1920; Stockder, A. H., German Trade Associations: The Coal Kartell, 1924; Tosdal, H. R., The German Steel Syndicate, Quarterly Journal of Economics, February, 1917.

coal fields, located on tidewater, have enabled Great Britain to maintain a dominant position in coal export trade.

Coal has played a major role in the rise of Great Britain to a position of first rank among the world powers. The relation of coal to the growth of manufacturing industries as manifested in the United States and western Europe applies with equal force to Great Britain. Not only are the important metallurgical industries of England and Scotland founded upon coal beds, but the vast textile industry may be said to owe its existence to an appreciable degree at least, to coal. The presence of coal and iron resources, inventive genius, and an energetic commercial people, gave to England the combination out of which emerged not only a metallurgical industry but also the many products—industrial machinery, factories, railroads, and ships—elements of an industrial order.

So extensive has been the industrial growth that this island empire with an area of 120,000 square miles supports a population of some 40 million people, nearly 90 per cent of which are more or less directly connected with manufacturing and commerce.

The industrial structure, thus created, was inseparably linked with the world-wide commercial activities of Britons. Ships laden with manufactured goods sailed to all parts of the world and brought back food and raw materials of manufacture. The routes of ocean trade were supplied with bunker coal mined from the tidewater coal deposits of Wales. In 1913, 92 per cent of the sea-borne coal trade of the world was of British origin.

In seeking the causes for this dominant position of Great Britain in the overseas coal trade, we find two factors preeminent: (1) The growth of foreign demand and (2) the cheapening of ocean transportation. The former is the outcome of the spread of population, development of railway transportation, industry, and agriculture abroad and in the colonies, and a rise of the material standard of living.

The cheapening of transportation costs presented unusual advantages to Great Britain over its potential competitors, principally Germany and the United States. British vessels, leaving the island for cargoes of raw materials, carried coal at low rates as ballast. Bunker coal, in large quantities, was needed to supply the trade carriers of foreign nations as well as the homeland. The advantages of low freight rates and the tidewater location of the prize Welsh steaming coals early enabled Great Britain to underbid her competitors in the world fuel markets. Coal, then, became the backbone of the shipping industry and opened the way for British goods to find outlets in the trade centers of the world.

This trade structure, however, contained certain weaknesses, which are now making themselves manifest. In the first place, the continued prosperity of British industry is dependent very largely upon the sale of manufactures among foreign countries. For nearly a century the natural advantages of the British Isles, coupled with political troubles on the continent, kept the competitive advantage in Britain's favor. The world abroad, however, was not standing still. In Germany, in the United States, and even in the Orient, manufacturing of steel goods and textiles was growing apace. The competition of home-made goods in these countries, frequently aided by protective tariffs, offered vigorous competition to British wares. The outcome could not be otherwise than an inevitable decline of British trade.

In the meantime the advantages of cheap export coal is passing with the gradual depletion of the better-located and richer coal seams. The coal resources of England are far from exhausted but the coal-mining industry has entered into a stage of increasing costs. This factor would inevitably, if almost imperceptibly, react unfavorably upon the trade advantages of the island, if not interrupted by external events. Such an event did occur in the World War, whose aftermath had a disrupting effect on British industry. Without attempting a detailed discussion or description of the conditions of the British coal trade and industry in the post-war decade, we may point out that this period witnessed a substantial increase in the productive capacity of coal mines in Germany, the Sarre, Poland, and Russia. Mining efficiency, especially in Germany, has also improved so that England faces powerful competitors in the coal trade eager to enter the world's markets.

The conditions under which British trade flourished in the nineteenth and early twentieth centuries are gone. For many years the world's leading workshop, England, has witnessed the rise of rival industrial districts with richer resources and better equipment. Like Britain these districts are striving for world markets and not without success. A powerful nation faces the problem of reconstructing its commercial and industrial policy to meet the conditions of today. Can a solution to this problem be found?

CHAPTER X

CHARACTERISTICS OF PETROLEUM AND DISTRIBUTION OF OIL RESOURCES

THE manifold aspects of petroleum, its geology and geography, the technology of production and transportation, and the manufacture of its many and varied derivatives, together with the political and economic aspects of the industry, if treated fully, would occupy many volumes. The petroleum industry is the second largest business in the United States, which is to say, in the world, and its many derivatives are so essential to the maintenance and prosperity of industrial civilization that the outline and features of this business should be made known to the public. An industry, which in the brief span of three-quarters of a century, has revolutionized the transportation system of the world, which supplies motive power for automobiles and ships, which heats houses, and lubricates the wheels of industry, deserves the careful study of men of all occupations and pursuits.

The rise of petroleum to a commanding position of rivalry with coal is accounted for only by the unique characteristics of this fuel. Coal as a source of power is confined largely to raising steam under stationary, marine, and locomotive boilers. Petroleum provides a group of fuels that are adaptable to the light motors of airplanes, automobiles, motor trucks, small engines, as well as to the heavier Diesel engines for ships, naval vessels, and stationary power plants. Its versatility in the power field moved the late Secretary of the Interior, Franklin K. Lane, to say in one of his annual reports:

> Petroleum is a priceless resource, for it can never be replaced. Trees can be grown again upon the soil from which they have been taken. But how can petroleum be produced? It has taken ages for nature to distill it in her subterranean laboratory. We do not even know the process. We may find a substitute for it, but have not yet. It is practically the one lubricant of the world today. Not a railroad wheel turns without its way being smoothed by it. We can make light and heat by hydroelectric power, but the great turbines move on bearings that are smothered in petroleum. From it we get the quick-exploding gas which is to the motor and the airship what air is to the human body. To industry, agriculture, and the pleasures of life, petroleum is now essential.

The upward curve of petroleum output rises faster than any other raw material. Why? The answer lies in the rapid expansion of those tools and machines that must have petroleum products as fuel and as lubricants.

If the petroleum is of so great importance in turning the wheels of industry and transportation, equally significant is its function in smoothing the bearings upon which these wheels turn. Little thought has been given to this unique function of oil—that of saving power. Nevertheless, machinery without lubrication is unthinkable; adequate lubrication saves energy and makes it available for use as well as adding to the life of the machine.

COMMERCIAL PRODUCTS OF PETROLEUM

The petroleum industry occupies its important position in industry because of the wide and diverse range of usefulness of its products. Each product, in fact, performs a peculiar and distinctive function which is not met with adequately by any substitutive or competitive material. All occupy places of importance. A description of the products must invariably begin with gasoline as the product of greatest value.[1]

Gasoline may be considered as a mixture of hydrocarbon liquids of high volatility suitable for use as a fuel in the internal combustion engine. It is not a homogeneous substance and no hard and fast line can be drawn which separates it from the next fraction obtained from crude oil, kerosene. The chief users of gasoline are the automobiles and motor trucks. The increase in the output of gasoline is essentially a reflection of the phenomenal rise of automobile registration. The outstanding achievement of the refining industry has been its ability to meet the constantly increasing demand for gasoline, that is, to keep pace with the growing use of the automobiles, which are estimated to take at least 85 per cent of the total consumption. This product is the most profitable to the industry and the effort of the refiner has been to increase the percentage yield of gasoline from crude oil. Through various factors, such as improvements in refinery technology, recovery of gasoline from natural gas, and cracking, the yield of gasoline from crude has risen from 18 per cent in 1916 to 37 per cent in 1927.[2]

Kerosene is the general name applied to the group of refined petroleum fractions employed as fuel for lamps and for cook stoves requiring a fuel less volatile than gasoline.

[1] Boyd, T. A., Gasoline: What Everyone Should Know about It, 1925.

[2] Petroleum Facts and Figures, Second Edition, 1929, American Petroleum Institute, p. 142.

Kerosene, in the early days of the refining industry, was the principal commercial product of crude oil. For over 40 years its use expanded until this illuminant penetrated literally to the uttermost corners of the globe. It would be difficult to estimate the value to the world at large of this cheap and convenient source of light, which has aptly been termed "one of the greatest of all modern agents of civilization." It was the chief illuminant before the advent of gas and electricity, and still occupies an important place as such in rural homes. The decline of kerosene and the rapidly mounting demand for gasoline has brought about a change in refining practice so as to carry more of the kerosene components into gasoline for use as motive power. Today the product finds its chief outlet in rural lighting, in domestic heaters, and for export trade.

Gas Oil and Fuel Oil.—Fuel oil is the residue remaining after the available gasoline and kerosene have been extracted from the crude. It contains the heavier and less volatile hydrocarbons including the lubricating oils, wax, or asphalt, unless these latter ingredients are extracted in the "complete" refining process. Fuel oil fills a wide variety of uses, all of which may be placed in three groups, viz., (1) as a raw material for cracking gasoline, (2) as a substitute for coal, and (3) as a competitor of coal. The growing demand for gasoline, already referred to, is being met by an increased percentage recovery from crude oil through cracking of the heavier distillate, fuel oil. When the price of fuel oil is low, the refiners in important market areas find it profitable to purchase fuel oil, to a large extent, from California, the Gulf Coast, and the Mid-continent, for cracking purposes. As a competitor of coal, it is being used on railroads, ships, central stations, navy transports, in several of the manufacturing industries, and in domestic heating. As a substitute for coal, fuel oil supplies the energy requirements for the industry, transportation, agriculture, and for domestic use in California where coal is absent and where the cost of its importation would be excessive.[3]

Lubricants.—The lubricating materials suitable for the high-speed, high-temperature machinery of today, are obtainable in sufficient quantities only from petroleum. Lubricants, obtained from vegetable sources and animal fats, met the needs of the simple machines of a pre-industrial age, but only the lubricating oils from petroleum can be used in modern machinery without decomposition and loss of lubricating properties. The whole development of our machine civilization during the past half century has been made possible by petroleum lubricants;

[3] Swanson, E. B., National Survey of Fuel Oil Distribution, Report of the U. S. Bureau of Mines, 1928.

its future maintenance depends upon our ability to secure an adequate supply of these heavy non-volatile oils. Other petroleum products which may be mentioned are paraffin wax, petrolatum, asphalt, road oils, and petroleum coke.

Nature of Oil.—Crude petroleum, as the raw or unrefined product is often termed, is an oily liquid varying considerably in appearance according to the locality from which it comes. It is an extremely complex mixture of organic compounds, chiefly hydrocarbons, but substances containing sulphur, oxygen, and nitrogen are also present in small amounts. If crude petroleum is exposed to the air, it gradually thickens until a solid residue is left. The first product given off is a natural gas; then liquid components evaporate in the order of their lightness; and the final residue is composed largely of either paraffin wax or asphalt. Petroleum is thus seen to be a mixture of different liquids dissolved in one another and holding in solution also natural gas and solid substances. This conception correlates natural gas as a by-product of petroleum and affords a simple epitome of the changes more rapidly induced when petroleum is subjected to refining. The asphalt lake of Trinidad and ozokerite deposits of Galicia and Utah represent natural residues from the prolonged evaporation or natural distillation of petroleum. While petroleums vary considerable in character, they fall chiefly into two classes according to whether the residue yielded is predominantly paraffin wax or asphalt.

THE WORLD'S OIL RESOURCES

He who attempts to estimate the world's reserves of petroleum engages in a hazardous undertaking. Men of high repute in the field of oil geology have made these attempts in the past and, as shown by subsequent production records, have fallen far from mark.[4] The estimates, guesses, and beliefs advanced from various quarters have differed all the way from a few years' supply to that of an almost inexhaustible reserve. Prudent observers no longer make definite predictions and, with equal prudence, leading oil refiners do not conduct their business without an eye upon possible exhaustion and the need of finding

[4] See Day's estimate in 1908, U. S. Geol. Survey Bull. 394, 1909; Arnold's estimate, in Economic Geology, December, 1915; U. S. Geol. Survey estimate of 1916 in a report to Congress, 67th Session, Senate Document No. 310, 1916; David White's estimate presented before the Society of Automotive Engineers, February, 1919; joint estimate of the oil reserves of the United States as of January 1, 1922, by the American Association of Petroleum Geologists and the U. S. Geol. Survey, published as a press report of the Survey, 1922; reserves as estimated by a Committee of Eleven of the American Petroleum Institute in American Petroleum: Supply and Demand, 1925.

a substitute raw resource from which may be obtained the liquid fuel so valuable to industry and so priceless to our material comforts.

The changed views of the extent of our underground oil reserves show increased potential recoverable totals, and thus indicate a later ultimate date of depletion. Several factors have created these more favorable conceptions of the situation: (1) new and more accurate methods of geological exploration, (2) the discovery of deeper prolific sands, (3) improved operating methods, and (4) the rejuvenation of partially depleted fields.

The application of geophysical prospecting methods to the problems of applied oil-field geology has greatly improved the technique of determining the location, shape, and extent of structures favorable to the accumulation of oil. By the use of methods such as the gravimetric, the magnetic, the seismic, and the electric, many of the hazards of "wild-cat" exploration are eliminated and the oil drill may be started with more definite assurance of commercial production.

Deep drilling has resulted in the discovery of prolific horizons at depths which a few years ago were unattainable. Then the drilling of a well to a depth of 5000 feet was considered an outstanding accomplishment, fraught with extreme difficulty and hazard; today most of the problems involved in reaching a depth of 10,000 feet have been solved.

The improvement in operating technique is constantly increasing the percentage of recovery of oil from the sand and a new interest has developed in some of the older fields, from which appreciable supplies of oil are now being recovered as a result of rejuvenation. This means harvesting a second crop of oil, and in the Bradford and Allegheny fields of Pennsylvania alone new methods are estimated to have added 600 million barrels to the ultimate recoverable supply.

Better technique in drilling and completing wells, the rational development of pools without competitive drilling, the maintenance of gas pressure in the new fields, and the restoration of pressure in partly depleted fields are all factors of outstanding importance in increasing the total production of crude oil from the natural reservoirs of this country. This increase in ultimate recovery from fields in excess of the original estimates—which in specific terms referred to the oil "recoverable by the production methods then in use"—together with the discovery of deep prolific sands and new fields, explains the inconsistencies between previously estimated reserves and the enormous quantity of oil produced subsequent to the making of such estimates.

The task of locating and measuring the world's oil reserves by geological survey and prospecting will be a continuing one, and, as information of this nature accumulates, future estimates will approach a greater degree of probability. For the present we can concern ourselves with existing oil-producing fields, their geographic location, their relative importance, and the present and past performance with a few remarks about their promise for the future. Geographically the oil-producing fields are widespread. Table IV shows appreciable production in three continents and eight countries, for 1929, while seventeen other countries made minor contributions. These eight countries, however, are outstanding in that they are yielding over 95 per cent of the present output, and have also been the principal contributors in the past.

TABLE IV*

WORLD PRODUCTION OF PETROLEUM IN 1929 AND FROM 1857–1929

(Figures in thousands of barrels)

	1929		1857–1929	
	Barrels of 42 U. S. Gallons	Per Cent	Barrels of 42 U. S. Gallons	Per Cent
United States	1,006,000	67.6	12,249,675	65.5
Venezuela	137,000	9.2	380,944	1.4
Russia	103,000	6.9	2,437,760	13.6
Persia	45,250	3.0	345,420	1.7
Mexico	44,689	3.0	1,559,887	5.1
Netherland East Indies	37,924	2.6	429,086	2.6
Rumania	34,930	2.3	339,770	1.8
Colombia	20,385	1.4	63,930	0.3
Peru	13,404	.9	108,168	.6
Trinidad	8,810	.6	55,201	.3
Argentine	8,800	.6	61,108	.3
India, British	8,470	.6	198,479	1.0
British Borneo (Sarawak)	5,277	.4	41,214	.3
Poland	4,953	.3	218,262	1.2
Japan (including Taiwan)	2,010	.1	58,104	.3
Egypt	1,866	.1	19,145	.1
Ecuador	1,351	.1	3,896	
Sakhalin, Russian	1,160	.1	2,575	
Canada	1,133	.1	28,485	
Iraq	798		(†)	
Germany	711		19,990	.2
France	516	.1	5,406	
Czechoslovakia	93		1,186	
Italy	44		1,445	
Other countries	30		1,207	
Total	1,488,604		18,632,086	

* Compiled from figures published by the U. S. Geological Survey.

† Included in other countries.

The history of individual oil fields and districts has been one of rise and decline. Some have had a long period of growth followed by an equally slow decline, others have risen quickly or fallen quickly, or both. It is reasonable to believe that the history of larger areas of countries will follow similar production curves, hence the oil industry is vitally interested in the production performance that each country or major district will show. Furthermore, the industry is also interested in areas which show indications of promising oil or of present fields that give promise of rising to positions of major importance. In attempting to answer this question we are compelled to study the production records of countries, from the beginning of their published statistics and to rely upon the published reports of surveys that have been made. These reveal information that together with the domestic oil industry make worthy of special discussion the foreign oil fields of Russia, Mexico, Rumania, Venezuela, Colombia, and Peru.

Venezuela.—The remarkable rise of Venezuela among the petroleum-producing countries, from an output of 120,000 barrels in 1917 to a position second only to the United States, is an instance of rapid exploitation under favorable legislative conditions. A large proportion of Venezuela's production is coming from four fields: La Rosa, Laguinillas, Ambrosia, and Mene Grande, all on the eastern shore of Lake Maracaibo. The Maracaibo basin in many physical and geological respects is similar to the California oil provinces. The Venezuelan fields are of especial significance to the United States because of the nearness to the refineries of the Atlantic Seaboard. The distance from New York City to Maracaibo Lake is about the same as the water route to Galveston, Texas. The importation of Venezuelan oil into the United States has been, in a large measure, causing concern among the producers in the Mid-continent field. With a low cost of production, and the cheap transportation to both Gulf and Atlantic Coast refineries, operators in Venezuela have been in a position to produce and sell at a profit in the face of an unfavorable domestic market for crude. Imports of crude oil from Venezuela and other South and Central American countries have attained a more important position in the East Coast refinery market each year. According to the Bureau of Mines, imports increased from 21 million to 50 million barrels from 1927 to 1929.

The large acreage of proven oil lands and the constant improvements in pipe-line facilities from the fields to deep water promise to make Venezuelan oil an important factor in the domestic oil trade of the United States for many years.[5]

[5] Hopkins, E. B., and Wasson, H. J., Venezuela's Remarkable Oil Development, Oil and Gas Journal, December 29, 1927, p. 49. Hunter, C. M., The Oil Fields of the Maracaibo Basin, Jour. Inst. Petroleum Technologists, Vol. 12, 1926, pp. 235–256.

Mexico has long been an important source of supply to American refiners. This nation at one time ranked second as an oil producer and in 1921, the year of peak production, accounted for 25 per cent of the world's output. Since then the decline has been constant until in 1928 its share of the world's oil was less than 4 per cent. The decline is explained partly by adverse legislation but also by the natural decline of several of the oil-producing fields.[6]

The decline in Mexico is being offset by increases in Venezuela and Colombia, both of which will increase the supply of oil available to the Atlantic Coast refining industry.

Russia [7] bids fair to be among the important producers outside of the United States. It is exceeded only by Venezuela. The principal oil-bearing regions of Russia may be divided into six areas, as follows: Baku, Grozny, Kuban-Black Sea area, Emba-Ural, Fergnana, and Sakhalin. There are other localities in which deposits of petroleum have been found, but in these its existence in commercial quantities has not been proven as yet. In many cases the inaccessibility of the regions has militated against their development and very little attempt has been made to explore them geologically, since, no matter how rich they might be, a large outlay of capital would be necessary in producing and marketing their oil. The fields of the northern end of Sakhalin Island off the east coast of Siberia were surveyed for petroleum deposits many years ago, but no exploitation of any note was undertaken. At present this area is in the hands of the Japanese, who are reported to be actually producing oil. The Apsheron Peninsula, on the south shore of which is situated the city of Baku, is the richest petroleum area in Russia.

The resources of Russia have been the subject of study by Russian geologists under the Soviet who estimate 900 million tons in proven areas. This can be regarded only as a tentative figure since many unexplored areas exist where conditions favor the occurrence of oil.[8]

The Oil Fields of the United States.—The oil supply of the United States is obtained from widely separated regions or "fields," eight in number, covering portions of nineteen states. Although these eight fields cover, in the aggregate, a large area, and span a wide stretch of territory, the really large yields of oil are obtained from relatively small areas. The location and relative importance of these fields is shown in

[6] Clark, J. Rueben, The Oil Settlement with Mexico, Foreign Affairs, Vol. 6, No. 4, July, 1928, pp. 600–614.

[7] Otis, W. A., The Petroleum Industry of Russia, Trade Information Bulletin 263, Bur. of For. and Dom. Commerce, 1924.

[8] Redfield, A. H., Petroleum Resources of Russia, Bull. Amer. Association of Petroleum Geologists, Vol. II, No. 5, May, 1927, pp. 493–513.

Table V. The dominance of the Mid-continent and California fields is immediately evident.

TABLE V *

CRUDE PETROLEUM PRODUCED IN THE UNITED STATES

(Thousands of Barrels of 42 U. S. Gallons)

	1928	1929
Appalachian	31,059	33,757
Lima-Indiana	1,670	1,549
Michigan	594	4,354
Illinois and S. W. Indiana	7,425	7,216
Mid Continent	553,125	584,751
Gulf Coast	46,591	55,574
Rocky Mountain	29,199	26,360
California	231,811	292,037
Total	901,474	1,005,598

* From U. S. Bureau of Mines, Annual Petroleum Statement, (mimeograph).

The Appalachian Field, the first producer in the United States, extends across western Pennsylvania, eastern Ohio, through West Virginia and Kentucky, with extensions into southern New York and northern Tennessee. This field supplies less than 5 per cent of the nation's output. Although there are over 140,000 producing wells in the area, the output is less than a barrel per well per day. The peak of production for this area, never very large, was reached about 1900 and since then it has experienced a slow decline. The oil pools are apparently shallow in depth and small in size. Oil will undoubtedly be recovered for a long time, probably another century, but within a decade or two, the total output will have declined to a negligible quantity.

The oil of this field is a high grade, of paraffin base with a high content of gasoline and cylinder stock. This factor combined with the nearness to market is responsible for higher than average prices and the profitable operation of wells with a fraction of barrel output per day.

Three other oil fields in the east, the Lima-Indiana, Michigan, and Illinois-Indiana, together produce only about 1 per cent of the nation's yield and seem to be declining. Illinois reached its peak about 1908.

A casual study of the production of each field immediately reveals the dominant importance of two fields in four states, the Mid-continent field in Oklahoma, Kansas, and Texas, and the California fields, with

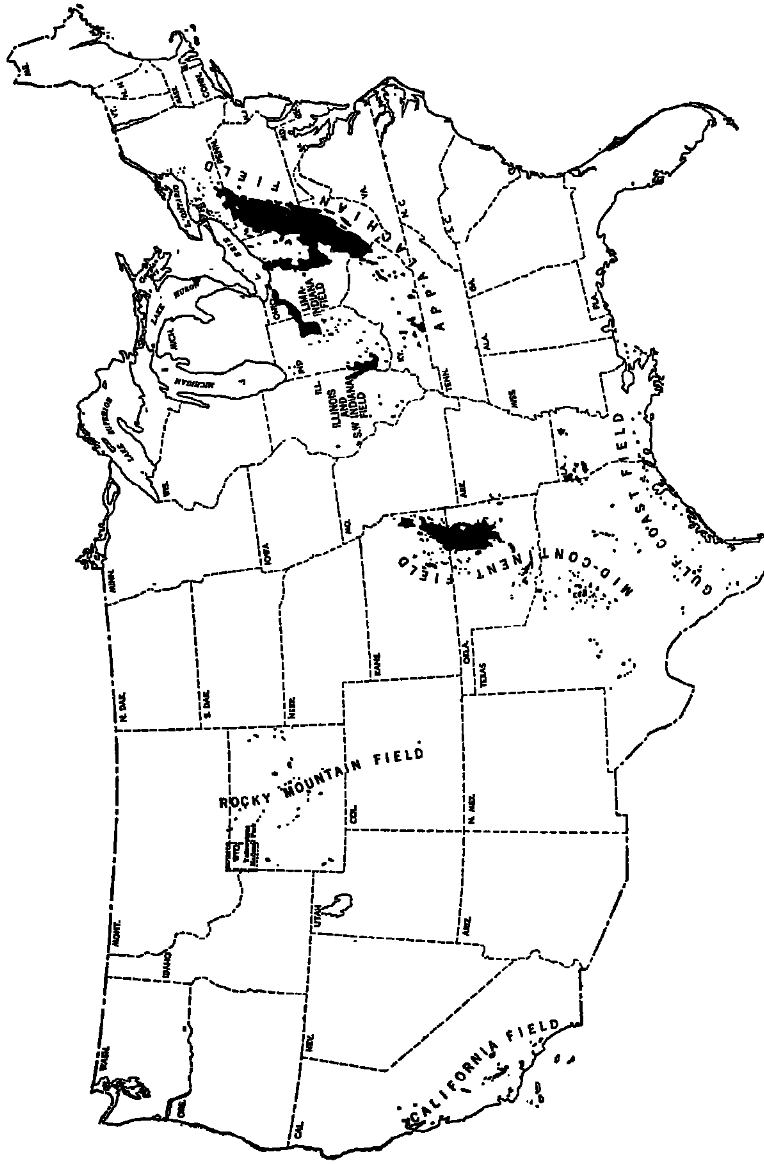

FIG. 6.—OIL FIELDS OF THE UNITED STATES.

appreciable production from the Gulf Coast and Rocky mountains. The Mid-continent field yields more than all the remaining producing areas. This field occupies a broad basin extending from the Ozark and Ouachita Mountains on the east to the high plains of Kansas and the Pecos country of Texas and New Mexico on the west. The northern limit of production lies in Kansas and it extends southward through Oklahoma into Texas. In fact, the southern and western limits are not yet definitely known. Within this oil empire, certain well-defined areas of intensive production are evident, in east Central Oklahoma, southern Kansas, north Texas, the Pan Handle, West Texas, and minor areas, also in this state. It is an area notable for large pools which have produced phenomenal quantities of oil, and sometimes so lavish in their output as to upset the crude oil market and cause embarrassment to the oil producers.

Notable among these pools are as shown in Table VI.[9]

The **West Texas** area, in which Crane, Upton, Pecos, and Winkler counties are the leading producers, is worthy of special notice because of its rise to prominence in 1927, and the promise of being a leading producer for many years to come. Discovery of this prolific area was hastened by a chance attempt to find oil in 1922, and by 1928 it easily became the outstanding area of the country. The wells are notable for their large initial production—5900 barrels per well in April, 1928, as compared with 1900 barrels in Long Beach, California, or 500 barrels in Seminole for wells completed in the same period.

California.[10]—California is one of the most amazing oil-producing and refining sections of the world. It is producing and refining more oil than the combined efforts of Algeria, Russia, Persia, Peru, Venezuela, Dutch East Indies, Rumania, Sarawak, Argentine, Poland, Trinidad, Colombia, France, Germany, India, Japan, Formosa, Egypt, Czechoslovakia, Canada, and Italy.

Although the discovery of oil in California dates back almost to the Drake well, the greater part of California's production has been recorded since 1920. The peak of production occurred in 1923 when a total of 263,728,895 barrels were produced.

The California field may be divided into three distinct areas. One covers both sides of the San Joaquin valley, known as the "Valley Field"; another takes in the many small and separate districts in the mountainous Santa Barbara and Ventura Counties; and the third comprises the districts of the southern coastal plain in Los Angeles and Orange counties.

[9] Oil and Gas Journal, February 2, 1928, p. 29.

[10] Egloff, G., and Chandler, A. R., Universal Oil Products Company, 1924.

TABLE VI

PRODUCTION RECORD OF LEADING POOLS FROM THEIR BEGINNING TO JANUARY 1, 1928

Year Opened	Field and State	Total Production, Barrels	Producing Acreage	Recovery per Acre, Barrels
1901	Midway-Sunset, California	616,948,073	35,364	24,323
1896	Coalinga, California	304,578,674	11,200	27,194
1912	Cushing, Oklahoma	283,894,274	21,850	12,993
1900	Kern River, California	265,941,977	6,521	40,772
1875	Bradford, Pennsylvania	261,182,000	85,000	3,072
1921	Long Beach, California	260,110,233	1,360	191,257
1922	Smackover, Arkansas	245,733,779	21,560	11,397
1916	Butler County, Kansas	207,679,731	23,750	8,744
1889	Salt Creek, Wyoming	191,529,122	20,480	9,352
1906	Glenn Pool-Kiefer, Oklahoma	187,018,535	18,590	10,060
1920	Santa Fe Springs, California	169,028,907	1,338	126,329
1920	Burbank, Oklahoma	149,008,605	20,150	7,395
1913	Healdton, Oklahoma	148,490,999	7,340	20,235
1926	Seminole area, Oklahoma	146,362,842	10,470	13,979
1920	Huntington Beach, California	126,964,839	1,752	72,470
1919	Burkburnett, Texas	125,704,548	18,080	6,952
1897	Fullerton, California	122,318,601	1,254	97,542
1902	Santa Maria, California	121,518,200	5,247	23,159
1906	Cadduo, Louisiana	119,786,380	32,200	3,720
1912	Coyote, California	117,115,462	2,100	55,769
1905	Humble, Texas	99,738,179	1,356	73,553
1922	Tonkawa, Oklahoma	96,692,111	3,420	28,272
1921	Mexia, Texas	84,038,338	3,704	22,689
1923	Powell, Texas	97,313,149	2,612	37,256
1901	Spindletop, Texas	83,601,501	390	214,362
1920	West Texas, Texas	82,423,667	11,880	6,938
1904	Sour Lake, Texas	71,124,077	3,645	19,512

The most striking feature of the fields in the Los Angeles basin is the enormous thickness of the oil sand and the limited producing area from which the enormous flow of oil comes. Here are located Santa Fe Springs, Huntington Beach, Inglewood, Long Beach, Rosecrans, Dominquez, Torrance, and Seal Beach, all of which lie within a 50-mile radius of Los Angeles. These eight fields, since their discovery, have produced 654,000,000 barrels of oil,[11] as well as large quantities of natural gas and casinghead gasoline. Operators cannot expect another series of fields in southern California comparable to those mentioned, due to

[11] Oil and Gas Journal, June 30, 1927, p. 37.

the fact that all of the major uplifts have been drilled and eliminated. All well-informed operators have recognized this for some time and the action of the Union, Shell, Standard, and others in tying up potential acreage in Ventura and Santa Barbara counties and in all sections of the San Joaquin Valley confirms the belief that California's future production will come from these fields. The Standard, through acquisition of the Pacific Oil Company lands, is in possession of a large acreage of proven reserves near Tulare Lake.

While it is generally agreed that California's future production is expected to come from that vast area known as the San Joaquin Valley, the potentialities of Ventura and Santa Barbara counties must not be overlooked, both of which have yielded several prolific fields.

The geographic position of California affects in a marked manner the organization of its petroleum industry. The vast output of oil cannot be marketed entirely on the West Coast, hence a considerable portion of the product, crude and refined, must be exported. The industry therefore divides itself logically into three parts, domestic consumption, crude exports, and export of refined products.

California oils, it should be noted, are classified as heavy and the gasoline content is somewhat lower than the average for the country. The gasoline yield in 1926 was 25 per cent whereas in 1921 it was only 14 per cent, the increase in the intervening years being brought about by cracking and recovery of natural gasoline from gas.

The handling of California crude is accomplished by a pipe-line system whose trunk lines extend from Los Angeles to San Francisco and whose gathering lines tap all the fields. The concentration of a number of flush fields within a limited area to refining centers has eliminated the necessity of long trunk lines but in its stead is an intricate network of smaller lines run from the 25 major and minor producing fields along the highways to the city.

The termination of pipe-line facilities at Los Angeles and San Francisco is particularly favorable to the marketing of crude and refined products by tankers to all parts of the world. Tanker fleets of the various refiners play an important part in the local market moving crude oil from Los Angeles to San Francisco and transporting refined oil from both areas to other normal domestic markets along the Pacific Coast, as well as to the Asiatic and Atlantic markets.

CHAPTER XI

BRANCHES OF THE PETROLEUM INDUSTRY

THE domestic petroleum industry includes producing, transporting, crude purchasing, refining, wholesale and retail marketing branches. A very large proportion of the business of each branch of the industry is handled either by large integrated companies whose activities compass the entire industry, or by concerns that have subsidiary or affiliated companies engaged in all branches of the business. A number of the larger companies own their own tank cars and operate fleets of tank steamers for coastwise or foreign trade.

Production.—The producing branch of the petroleum industry includes all of the activities incident to the exploration and location of oil lands, the drilling of oil wells, the extraction of crude petroleum from the earth, and its storage in field or "settling" tanks.

Production of petroleum begins with examination of the territory for its oil possibilities. The producing industry to-day employs the services of the geologist to survey the ground, map the positions of the strata, that is, the structure of the formations as far down as possible. He examines outcrops, logs of wells, topography, and all other available aids to determine the existence of as well as extent and boundaries of oil pools.

If a territory seems to be promising the next step is to secure legal control over the area. Seldom does the producing company purchase land outright. Leasing of the land for oil and gas rights is resorted to. The lease, which is an agreement between the land owner and the oil company, provides for the share of oil which the land owner is to receive (usually one-eighth), and specifies the time within which the lessee must start drilling. Other provisions are included, but the above two are the most important. Leases are sometimes acquired before prospecting is done in order to avoid speculation or prevent other oil companies from acquiring the property. When the geologist has become reasonably certain that he has found indications favorable to the discovery of oil, and when the preliminaries such as leasing agreements and acquiring titles have been completed, it becomes the driller's turn to step into the picture.

Production of oil is a large industry engaging the services of thousands of employees and requiring an annual expenditure of a half billion dollars. More than three hundred thousand wells contribute crude oil, in varying amounts, to the refineries, and ultimately to the users of oil products. Twenty thousand or more new wells are required each year to maintain an adequate flow of petroleum. The productivity of wells varies greatly, ranging from less than a half barrel a day to a high level of several thousand barrels in the prolific fields of West Texas or California. The average production is about eight barrels per day.

It may be observed that it takes only 20,000 wells, 6 per cent of the total, to supply 30 per cent of the oil output, and over 300,000 wells to supply the remainder.[1]

The large producers sometimes obscure the actual trend of the oil output in a district, for one pool, or even one well, may have an output sufficient to show an increase of production when the region generally is showing a decline. This may be illustrated by Oklahoma, in 1927, when the great Seminole field produced 136 million barrels of oil, completely overshadowing the decline over 1926 in the older fields of the state, a decline of nearly 40 million barrels. The usual history of an oil well, or group of wells, from an oil pool, is one of flush production immediately after opening followed by a rather rapid decline. The period of rapid decline may be followed by a long period of small but slowly declining yield. Some of the wells in the Pennsylvania fields, although yielding less than a half barrel daily, nevertheless have been producing for decades.

Oil Production Costs.—The cost of drilling new wells each year now exceeds a half billion dollars and is increasing. The well records of one of the largest companies in Oklahoma show a progressive increase in average well costs from $3169 in 1912 to $45,574 in 1928. Drilling to greater depths has been the principal factor in increasing the average cost of securing oil production. In addition to this must be cited the generally higher level of wages and cost of supplies. An important factor in adding to the cost of oil production is the expenditure on dry holes. Of the many wells completed each year, the records show that about 30 per cent are non-productive. Whether these wells are sunk by individual drillers or are a part of the operation of a large producing organization, they constitute a cost which must be charged ultimately to the production branch of the industry.

In view of the keen competition that exists in the oil industry, particularly in the production branch, the cost of producing oil is of

[1] Summary of Crude Oil Production in the United States, First Six Months of 1929, Oil and Gas Journal, July 25, 1929, p. 131.

vital interest to the individual producers and to the entire industry as well. Sound business management would dictate that every effort be made to introduce economies in the recovery of oil. It is quite evident that the average cost of wells will rise as deeper and deeper producing sands are being drilled. Economies, then, can be achieved only by increasing the average output per well. This can be obtained only by (*a*) a program of well drilling which will sink only as many wells as are necessary to drain a pool effectively, and (*b*) increasing the percentage of recovery of oil from the producing sand. In the drilling practices of the past, wells were sunk in relation to property lines rather than according to the best-known engineering practices of oil recovery. Far too many wells were put down in one pool, and each well in excess of those necessary for the recovery of the oil meant a direct waste of capital as well as an indirect loss resulting from incomplete or too hasty recovery of oil.

More economical production methods cannot be considered apart from the general problem of a constructive oil policy, hence a more extended discussion of the economic problems of oil production will be reserved for a later chapter.

Advances in Oil Production Practices.—The lowering of production costs through more complete draining of the oil sands is making progress in several directions. Among the methods in use or suggested are:

1. Water flooding of oil sands.
2. Use of soda ash in freeing oil from the porous reservoirs.
3. Use of gas and air pressure in pools.
4. Mining the sand.

In the flooding method, water is put into oil sands which have been exhausted by ordinary pumping methods but which are known to contain large quantities of oil. Detailed analyses of core drillings in the Bradford sand, in northwestern Pennsylvania, indicate an average oil saturation of about 55 per cent in these "exhausted" fields.[2]

The essentials of this method consist of drilling a number of wells into an oil sand. Into some of these wells water is pumped which moves under pressure into the oil sand and pushes the oil before it. The drillings are so arranged that the water-propelled oil is forced to move toward the "producing" or oil-recovery well.[3]

[2] Torrey, Paul D., Bradford-Allegany's Great Future, Oil and Gas Journal, February 27, 1930, p. 42.

[3] For a discussion of the principles employed in oil recovery by the flooding method see "Recent Developments in Flooding," by C. R. Fettke, presented to the A.I.M.E., New York, February, 1930, and published in the Oil and Gas Jour., February 20, 1930, p. 38.

The Bradford pool of northwestern Pennsylvania and adjacent portions of New York State and the Richburg pool of southwestern New York are the only pools where artificially conducted flooding drives on an extensive scale have proved economically successful. In other fields of the state of Pennsylvania this method has been tried with variable, but in general, encouraging results. While the method can by no means find general application in all oil fields, there are undoubtedly many sands in the Appalachian fields possessing characteristics that would adapt them to water flooding.

In the Bradford and Allegany fields, water flooding has established a reserve of approximately 600 million barrels of recoverable oil which would never have been obtained by natural methods of production.[4]

The use of soda ash was initiated by the U. S. Geological Survey in 1925 and field experiments are now being carried on by operators in the Bradford field. Rows of wells 150 feet apart are drilled in the experimental area and one row is treated with a water drive carrying sodium carbonate. About 50 pounds of the chemical are dissolved in one barrel of water and run into the wells. The procedure varies in regard to the number of days the solution should be used, but it is a common practice to force 50 barrels into a well after which water flooding is continued in the ordinary way. The theory is to loosen the film of oil surrounding each grain of sand and then flood out the released oil by the use of water. This process is still in the experimental stage and definite results cannot be determined until two or three years have elapsed.[5]

Air and Gas Lift.—The compressed-air process was adopted in 1911 and is known as the Marietta or Smith-Dunn process. In this process, air is forced through an oil sand under a 40 to 300-pound pressure, and any inert oil remaining in the interstices of the sand moves toward some producing well. The method became somewhat widely adopted in 1916. Production may increase rapidly within a few hours after the air is applied, and on the other hand several months may elapse before any improvement appears. The average increase in production is about three and one-half times the previous average daily recovery.

The compressed air moves the oil in several ways—first, by direct pressure; second, by going into solution with the liquid under pressure near the air well and then expanding near the producing well; third, by carrying off vapors. This method has been used in Ohio, Pennsylvania, Indiana, Kansas, Oklahoma, and California, and is usually applied to

[4] Oil and Gas Journal, October 27, 1930, p. 155.

[5] Nutting, R. G., Petroleum Recovery by the Soda Process, Oil and Gas Jour., October 18, 1928, p. 146.

wells in areas where the production has declined to a fraction of a barrel daily.[6]

The air-gas method is a variation of the Smith-Dunn procedure and is confined to one well rather than a series of inlet and outlet wells where the air or gas pressure moves the inert oil in an exhausted sand toward an outlet well.

The air-gas lift is bringing about profound changes in the production of oil. This system is primarily a matter of physics. It is operated on the principle of expanding gases. Air or gas (gas is more commonly used) is compressed to a predetermined pressure, and through a series of pipes is sent to the well head, and introduced into the casing or tubing. The gas is released at a point near the bottom of the hole, and the gas globules, mixing with the oil globules, expand, and as they expand, help lift out the oil.

The air-gas lift was applied for the first time at Seminole as soon as natural flow ceased and sometimes before. Previous application of the lift in other fields has been confined largely to wells that have been pumping for some time. The system of oil production serves several purposes depending upon the objectives desired. In the Seminole field the primary consideration was an increase in daily production and its success in that respect was unquestionable. The increased rate of production, however, contributed largely to the economic depression attending flush production at Seminole. The rate of production, then would seem to be an economic question rather than an engineering problem. The reduced price of oil in 1927 has more than offset any gain derived from increased production; the lift as applied in Seminole has not been an economic success.[7] The fault, however, does not lie with the air-gas method but in the overexpanded condition of the oil industry.

Another consideration in the use of the air-gas lift is that in the very deep and crooked rotary holes that have been drilled in recent years, it was often impracticable and even impossible to use the old deep well plunger pump. This problem was the chief reason for the revival of the air-lift in California.

A factor of no small importance in the use of the air-gas lift is its usefulness in reducing production costs, both as to installation and operating costs.

Lift application has demonstrated a better means of regulating the

[6] Lewis, J. O., The Rejuvenation of Depleted Fields, Complete Hearings of the Federal Oil Conservation Board, February 10, 11, 1926, pp. 49–65.

[7] Swarts, C. R., Bopp, C. R., and Morris, W. S., Preliminary Engineering Report on the Seminole Pool, Seminole County, Okla., U. S. Bureau of Mines, July, 1928.

pressure on the productive sand. The results indicate that with proper application of the lift an increase in ultimate production would be obtained over that of the usual methods—natural flow and pumping. Operators are striving to improve production methods for the purpose of increasing ultimate recovery. Effective control of the gas pressures in the oil pool will accomplish this purpose. Effective pressure control is indicated by gas-oil ratios. The slow rate of water encroachment in certain highly productive areas where the lift was used is indicative of effective pressure control. Pressure regulation will accomplish two very important results in production problems: (1) It will utilize to the fullest possible extent the energy contained within the reservoir gas; (2) it will retard the rate of water encroachment.

The gas lift is not a cure for all production evils, but where effectively operated it has the following advantages:

1. Regulates the rate of production.
2. Offers a means of effective pressure regulation.
3. Conserves formation gas.
4. Retards water encroachment.
5. Increases ultimate production.
6. Decreases the time of obtaining ultimate production.
7. Decreases lifting costs.
8. Offers a means for operation of deep wells where other methods fail.
9. Increases the rate of gasoline recovery over other methods.

Transportation.—Petroleum is carried from the fields to the refining centers by tank car, tank steamers, and pipe lines, of which the last is by all means the most important. The tank car has always been the chief reliance for the domestic movement of finished and partly finished products, and it still plays its role in providing an outlet for oil from new fields. Usually this is but a temporary expedient used until the pipe lines can be laid into the field. As early as 1865, in the infancy of the industry, wooden conduits were laid for short distances and oil was pumped through them from the wells to the nearest refinery. Today, the crude petroleum is gathered from the producer's field or settling tanks through a system of pipes called gathering lines. Gathering-line pipes are usually 4 inches or under in diameter. These small pipes connect with larger pipes and lead to gathering-line pumping stations. In highly productive oil pools, particularly when different producers own or control small tracts of land, there is an extensive network of gathering lines leading from the oil pool. In many instances several pipe-line companies have gathering lines in the same oil pool and sometimes in the same lease.

Gathering Lines.—Practically all of the crude petroleum produced in the United States is collected by gathering lines, and the great bulk of it is transferred to a trunk pipe line for transportation to near-by refineries, to inland or seaboard refineries, or to transportation to a seaport, from whence it is carried to a refinery in a large tank steamer. Since 1923 large quantities of California crude petroleum have been piped to Los Angeles harbor and from thence transported to the Atlantic Seaboard by tank steamer. In times of temporary overproduction the crude petroleum may be transported to a large "tank farm," where it is stored for use when consumption exceeds current supply. The crude oil in storage, which for some time has been sufficient to supply refinery requirements for half a year or more, is largely owned by large crude petroleum purchasing companies or by petroleum refiners.

Trunk-line pipes have a much greater diameter than gathering-line pipes. The trunk-line pipes of the large interstate pipe-line companies range from 8 to 12 inches in diameter, and in some cases from 4 to 8 lines have been laid parallel to each other in order to handle the tremendous volume of crude oil which is constantly being pumped hundreds of miles to large refining centers. To-day there are through pipe lines from Kansas, Oklahoma, and Texas to important refinery centers both in the interior and on the Atlantic and Gulf Seaboards. These lines run to Chicago, Buffalo, New York, Philadelphia, and Delaware Bay and south to Baton Rouge, Houston, and other refinery points in Texas.

Pipe-line transportation is the most convenient and economical means of shipping crude on land. The advantage of pipe-line over rail transportation is so great that no refining company has been able to attain any importance in the industry without the use of pipe-line facilities. In recognition of this advantage which access to pipe lines gave to a refinery, particularly when located far distant from an adequate supply of crude petroleum, Congress in 1906 imposed upon interstate pipe lines the obligations of common carriers, but the validity of the law was disputed and the question was not settled until the United States Supreme Court upheld the law in the "pipe-line cases" in 1914 (234 U. S. 548).

The significance of the pipe line in the development of the petroleum industry has been great. It has made crude petroleum independent of the railroads and through cheapness of operation has lowered the cost of petroleum products; it has freed the refineries from geographic allegiance to areas of production and permitted their establishment at strategic points in respect to consumption of products; it has permitted and induced integration of activities, with marked advantage to the consuming public, but not unaccompanied by hardships and abuses falling upon small units of the industry itself; and by stretching out to meet a growing area of exploitation, it has unified widely separated fields and enabled production to grow to its imposing size. The pipe line has woven the scattered strands of adventurous exploration into a steady flow of bulk raw materials.

Tank Cars and Tank Steamers.—The rail movement of crude oil and petroleum products is handled by tank cars. For transportation by sea, steel tankers fitted with non-communicating apartments, are employed for both crude petroleum and its bulk products. The development of the tank steamer has been an important factor in building up the coastwise movement of petroleum from California to the Atlantic Seaboard, as well as the import trade from Mexico and Venezuela.

Crude Purchasing.—The great bulk of the crude petroleum, not refined by the company producing it, is purchased by comparatively few large purchasing companies. Many of these companies are large refiners or are subsidiary to or affiliated with large refining companies. The remaining production is purchased by small refiners and by companies engaged mainly in producing and dealing in crude petroleum. As already pointed out, crude petroleum in all the oil fields of this country is collected or gathered from the thousands of oil wells by a system of pipe lines. When crude petroleum is brought to the surface of the earth, there is mixed with it varying percentages of water, sand, and other sediment. In order to separate the water and sediment from the crude it is run into tanks called settling tanks where the impurities are allowed to settle to the bottom of the tank before the crude is run into the gathering lines. The crude run into the gathering lines still contains more or less sediment, and the purchasing company usually makes a deduction of 3 per cent from the total quantity to cover this sediment.

When a producer first sells crude petroleum, or when new wells are brought in, the pipe-line company gathering the crude connects the producer's tanks with its gathering line. The cost to a pipe-line company of making a "connection" with a new producer or with a new lease varies widely from a few hundred dollars to $2000, or even more. In some cases in a given oil pool a producer may have his tanks connected with two or more pipe-line systems, but in practice many small producers are limited to but one purchaser because only one pipe-line system is available.

The large purchasing companies secure from the producer a signed contract usually termed a "division order," in which the producers guarantee that they are the legal owners of oil wells from which crude on a given lease is to be purchased. Usually the purchasing company takes the entire production, including the royalty interest, if any, and the division order indicates the proportion of crude going to the royalty owner and the producer or producers.

The Posted Price.—The method of buying crude petroleum, by which the crude purchasing company announces the prices it will pay for crude by posting them upon a bulletin board at its place of business, or of otherwise making its prices public, is termed by the industry "posting prices," and the price referred to as the "posted price." The bulk of the crude petroleum, not produced by companies that refine their own production, is regularly sold at posted prices to a comparatively small number of large crude-oil purchasing companies. In many cases these companies are also engaged in other branches of the petroleum business, such as crude-petroleum production, refining, and marketing.

REFINING

The manufacture of the various products from the crude is the function of the refining business. For this purpose refineries are erected in the oil fields and in the strategic marketing centers of the country. They vary in size and type from the small topping plant of 200 barrels daily capacity to the large refineries manufacturing a complete list of petroleum products and by-products.

Petroleum is a mixture of many hydrocarbons, which boil and vaporize at different temperatures. When a quantity is introduced into a still and subjected to gradually increasing heat, the lightest elements rise and escape as vapor. These vapors are then condensed. The lightest to come off are the naphthas and gasoline; then, at a somewhat higher temperature, kerosene vaporizes, flows away, and is in turn condensed. Next come the still heavier oils, which ultimately become lubricants, paraffin, and other products. In the refining of asphaltic crude the asphalt will not distil over and is left as a residue in the still and is then recovered for commercial use. Such is a simple statement of the bare elements in the process commonly known as "straight" refining.

This description of the refining process is, however, entirely inadequate if one wishes to portray the revolutionary developments through which the refining industry has moved and is still moving. Straight-run refining—that is, the physical separation, by distillation, of the commercial elements contained in the crude—has given way to cracking and hydrogenation processes, by means of which the valuable gasoline percentage can be increased, and less marketable fractions decreased. Originally, cracking served as a contributory source of gasoline supply; to-day it assumes a position of major importance. The hydrogenation process bids fair to inaugurate a third era in the history of refinery technology. This process, rather than competing with the various cracking methods, is adapted to the treatment of crude oils which cannot be satisfactorily refined otherwise.

Both types of process aim to increase the recovery of gasoline. The rapidly growing demand for this commodity created a condition whereby fuel oil—the other large fraction obtained from crude—was being manufactured in excessive quantities. Market demand was the impelling motive which brought forth these far-reaching changes in the refinery industry. Each will receive extended discussion in this chapter.

Scope of Refining.—Petroleum refining includes all the operations necessary to produce a finished material: distillation, acid or alkali treatment, and clay filtration. The separation of crude petroleum into fractions of different volatility is necessary in the refining of all crude petroleums. Chemical treatment removes impurities and undesirable substances out of the finished product. Percolation through materials such as fuller's earth is used to absorb and remove the coloring matter in the refined oils.

The most important distilling operations are as follows:

1. "Topping" of crude.
2. Complete distillation of crude oil (*a*) to cylinder stock, (*b*) to flux, and (*c*) to coke.
3. Redistillation of crude naphtha (the lightest fraction) to refined gasoline and kerosene.
4. Refining of lubricants.
6. Cracking by pressure distillation.

The simplest type of refining is "topping" or "skimming." It consists in distilling off from the crude oil the volatile constituents such as gasoline, kerosene, and possibly gas oil, and disposing of the remainder as fuel oil. Very often the topping plant includes a cracking unit for converting gas oil into gasoline. This type of plant represents a small capital investment, and is usually located in a producing area.

The complete refinery is designed to manufacture gasoline, kerosene, gas and fuel oils, lubricants, together with the by-products—paraffin wax, coke or asphalt. Where the end product is cylinder stock, the crude oil is treated by "straight-run" distillation since, in order to preserve the high viscosity of the cylinder stocks, cracking must be avoided.

The process of distillation "to flux" is employed on oils that are so high in asphaltic content as to be unsuitable for cylinder stock manufacture. The heavy residuum is used largely as a road material.

Distillation to coke differs from distillation to cylinder stock chiefly in that cracking of the wax bearing fractions and lubricants is desired rather than avoided.

The rerunning of the naphthas to make the finished gasolines and kerosenes is usually done for the purpose of improving the quality and regulating the volatility.

In response to changing demands for different petroleum products, refining operations have had to be adjusted so that the products in greatest demand could be supplied in sufficient quantity. The most striking and revolutionary adjustment came with the tremendously increasing requirements for gasoline, previously a waste product. To produce more gasoline, more crude oil had to be run through the refinery stills, and the running of more crude oil produced not only more gasoline but more of the other products which result from the process of refining, with consequent problems of disposing of such products. However, by improvements of old methods and processes and the inauguration of new ones, the industry has been able greatly to increase the yield of gasoline from the crude instead of that of kerosene and lubricating oil. The yield of gas oil and fuel oil, however, is the largest of any product and a market had to be found for them, largely in competition with coal.

The greater part of the crude petroleum of the United States is refined in the areas where it is produced; that is, in California and in the Mid-continent field. However, the increased use of tankers and the growth in number and size of pipe lines have been instrumental in establishing refineries in such areas as the Atlantic coast, where no crude petroleum is produced.

As would be expected from its nearly constant rate of production of crude oil, the Appalachian area showed the least gain in quantity of crude run to stills in the past ten years. The Indiana, Illinois, Louisiana-Arkansas, and California districts showed the greatest gains. Increased demand for petroleum products in the general area of Chicago was mainly responsible for the growth of refinery capacity there. The increase of refinery capacity in California, the major part of which came after 1922, resulted from an oversupply of crude, as well as from increased demand for gasoline.

The Oklahoma, Kansas, and north Texas areas which produce light crude mainly, has always been the leader in output of gasoline.

Although the discovery of the pools of light oil in the Los Angeles basin greatly increased the output of gasoline in California, oversupply and technical difficulties have retarded the installation of much cracking equipment, and the percentage is still relatively low.

The Atlantic Seaboard and the Texas Gulf coast are the main areas that produce kerosene. A large proportion of the output is exported, as the refineries of these two areas are advantageously situated for foreign trade.

California has always been the leading producer of fuel oil. The lack of coal in that state provides a market for greater quantities of fuel oil for industrial purposes, the most important of which is railroad consumption. The output of gas oil and fuel oil in California in 1929 amounted to 135 million barrels, equivalent to 64 per cent of the total crude run in that state, and to 36 per cent of the total output of gas oil and fuel oil in the country.

The trend of refinery operations seems to be toward a scattering of refinery centers coupled with increase in capacity in order to reduce production and distribution costs. The market area of a refining center is determined by cost of transportation, as it is the delivered cost that forms the basis of competitive sales. Occasionally, refiners attempt to expand their territory over relatively large areas either by building new or purchasing jobbing stations already established. The added outlet appears attractive on first thought but as soon as the freight cost to the consuming point is higher than the rate from a competitive refinery, it can only serve as a dumping ground for excess products and can not be expected to pay a profit commensurate to the refinery's normal market area. This overlapping of areas is partly responsible for the increasing costs of marketing.

In the beginning of the oil industry the refineries were located near the crude-producing fields. Production and consumption of refinery products did not justify the erection of plants at great distances from the source of crude but as consumption increased pipe lines were laid from the producing fields to these marketing centers and the crude piped and refined there in preference to paying the freight on the refined products.

This led to the laying of three pipe-line systems to the Chicago area from the Kansas and Oklahoma fields and then prompted the laying of a line from the promising Wyoming producing fields to a point in Missouri to connect with one of these Chicago lines. With cheap water transportation reaching the thickly populated Atlantic Coast states eight lines were laid from various points in the Mid-continent fields to the Gulf Coast to supply new refineries there or to enable the cheap transportation of crude to the Atlantic Coast plants. In addition, pipe lines were laid from the eastern states to connect with two of the Chicago lines. In effect, this system of lines made possible the building of refining units at strategic marketing points and afforded quick service to consumers as well as cheapening the delivered cost.

Those refiners located in areas where production exceeds consumption are naturally trying to extend their marketing territory by securing lower freight rates into the thickly populated areas and on the other hand, the railroads have generally contended that existing rates are such as to afford only a bare operating margin of revenue. When this point is reached it must be recognized that the logical marketing territory for a refinery center is then defined.

The Effect of the Panama Canal.—The Panama Canal has had an important economic influence on the petroleum industry. Prior to 1922 the bulk of the movement of crude petroleum and refined products was westward. The discovery of the prolific fields of the Los Angeles basin, the decline of the Mexican fields, and the oversupply of ships caused a reversal in the movement which culminated in 1923 in a record eastern shipment of California crude petroleum—52,350,000 barrels. During the same year 3,369,000 barrels of refined oils were also shipped from California through the canal to eastern ports in the United States. Since then the shipments of crude oil have decreased and those of refined oils have increased, so that in 1925 the latter nearly equaled the former. In 1925 gasoline and tops comprised the major part of the shipments of refined oils from California, but since 1926, the shipments of gas oil and fuel oil have taken the lead. Much of these latter oils are eventually cracked into gasoline, hence the economic significance of California oil on the gasoline market of the Atlantic Seaboard.

Cracking.—The process of cracking the heavy oils of petroleum, shale oil, coal tar, etc., into lighter and more volatile oils suitable for motor fuels changed the entire character of the oil industry. The shortcoming of the straight-run method of refining was that the market would not absorb the various constituents or any grouping of them which could be made in the proportions in which they occurred in the various crude oils. Almost from the outset of the business there arose a preferential demand for one product in quantities far exceeding its relative proportion in crude oil; all efforts to build up outlets for the other products to make a balance failed. The only remedy was to convert products of one grade into products of another.

About 1911 the demand had shifted away from kerosene and toward gasoline to such an extent that a new conversion method was quite obviously needed. William H. Burton first produced a practical solution of the problem in the pressure still. He discovered that by treating a definite fraction of oil under a definite pressure and at a definite temperature range, it was possible to obtain large yields of gasoline by cracking. About 1911 Dr. Burton put the first high pressure still into operation.

Since that date the improvement and utilization of oil-cracking stills has continued without interruption. To-day few refineries can operate profitably without them and the automobile industry could scarcely have reached its present size without cracking to supply the necessary gasoline. Large sums of money have been spent in developing and improving these processes and so rapid is technical progress that the art of cracking is itself undergoing constant change. The early cracking stills were of small capacity and limited to the use of kerosene or the lighter fractions of fuel oil as their raw materials. The modern cracking plant has a much larger capacity, is capable of cracking almost any type of oil, kerosene, distillate, fuel oil, topped crude, and many of the crudes themselves, into gasoline with yields from 50 per cent to 75 per cent. With improvements in cracking stills has come about also a reduction in the per barrel cost of cracking.

The cracking process is a chemical operation accomplished with the aid of heat and pressure. The heavy oils are broken into lighter and simpler elements, such as compose gasoline oils, with free gas and coke coming off as by-products. The production of cracked gasoline takes place when oil is heated to a temperature of from 800° to 900° F., under a pressure of 200 pounds more or less varying with the type of oil treated. Cracking differs from the straight-run process in that the latter merely effects a physical separation of the crude oil into its commercial constituents whereas cracking converts a heavier fraction into a lighter one.

The rise of the cracking industry and the increasing proportions of cracked gasoline in the motor fuel supply is a consequence of the tremendous demand for gasoline. Petroleum refining industry is an example of a joint-product industry, the principal manufactured products being gasoline, kerosene, fuel oil, and lubricants. The demand for gasoline, occasioned by the rapid expansion of the automobile industry, far outstripped that of the other products, particularly fuel oil, which constitutes the largest fraction obtained from the crude. As a consequence fuel oil prices were exceedingly low in comparison with gasoline. Efforts to dispose of fuel oil by pushing the use of domestic oil burners, in motor ships, on railroads, and for industrial heating, were inadequate in the face of an ever-mounting supply. The decline in output of the lighter high-gasoline crudes of Pennsylvania and the rapidly increasing output of heavy crudes further served to amplify the supply of fuel oil. Moreover, the potential competition of coal in the fuel oil market served as an effective check toward the expansion of this market to a point where demand would cause prices to rise. In fact, a rise in price in fuel oil in 1924 and 1925 brought about a decline in the use of fuel oil consumed in direct competition with coal. The decreased consumption of fuel oil for such uses as raising steam, etc., is due to the cracking process. Fuel oil has become a raw material for gasoline manufacture in competition with crude oil and as long as there is a surplus of fuel oil, the value of straight-run gasoline can not be higher than the cost of gasoline obtained from fuel oil plus a reasonable profit. With the cost of cracking gasoline from fuel oil regarded at 5 cents a gallon, fuel oil itself selling for 50 or 60 cents a barrel [8] and the selling price of gasoline at 8 to 10 cents a gallon wholesale, the profitableness of cracking operations applied to fuel oil is evident.

As cracking expands, the differential in the price between fuel oil and gasoline will be narrowed until a balance is reached beyond which it is unprofitable to go. After that further supplies of gasoline will be obtained from the direct cracking of fresh accessions of crude.

The changing character of crude oil towards a heavier type is placing an added emphasis upon the position that cracking is to occupy in the refining industry. Instead of depending upon lighter crude oils for the major source of gasoline, the cracking process in its present state, permits of the treatment and conversion into gasoline of such heavy crudes as Smackover, Seminole, California, as well as the oil from Mexico, Persia, and Venezuela.

Economies of the Cracking Process.—The economies made possible by the extension of the cracking process occur in conservation of crude, in lower refining costs, and in increases of value of the products. This process is the most effective force in crude oil conservation. Due to the fact that 40 per cent of our gasoline is made by cracking, it is necessary to produce far less crude than would be required if the cracking process were not used.

Without the advent of the pressure still, it is doubtful if the refiner could have kept pace with the rapid and tremendous increase in gasoline consumption. Had the refiner attempted to increase his skimming facilities to meet the gasoline consumption, obviously the fuel oil market would have been glutted, hence demoralized. Fuel oil has been placed on the market for combustion under boilers in direct competition with bituminous coal because of a lack of other means of dis-

[8] 1929 prices.

posing of it. In fact frantic efforts were made to create a market for the product. Day points out that during the period 1922 to 1925 fuel oil was being sold at a loss, necessitating a tax on the gasoline, kerosene, and lubricating commodities to carry the burden of disposing of the fuel oil.[9] It is interesting to note that, in 1928, out of the 72 refineries shut down in the United States, only 10 were listed as having cracking equipment, and of those, the plants were composed of antiquated installations of early design.[10] The time is past when a refinery can successfully operate on the old principle of skimming kerosene and gasoline and selling the balance of crude as fuel oil. Cracking plants have become a necessity to every refiner who wishes to continue his operations on a profitable basis.

Vapor Phase Cracking.—The principal cracking processes in operation heretofore have been the type known as liquid phase, that is to say, a process where cracking of the oil in a liquid state is accomplished under high temperatures and pressures. A new process has been introduced which promises to effect reductions in cost as well as eliminating the dangers accompanying the use of high pressures. The heating of the oil is accomplished by mixing oil vapor under ordinary pressure with an inert gas preheated to such a temperature that the mixture of vapor and gas will have the desired cracking temperature. The heating of the inert gas is accomplished in hot blast stoves such as are used in connection with iron blast furnaces. The cracking chamber is lined with refractory brick to retain heat and prevent corrosion of the metal exterior. This insures a long life with low amortization costs. The yield of gasoline is said to be higher than in the liquid phase process and the product possesses higher anti-knock properties. Long life, minimum hazard, freedom from corrosion, and low capital costs are the principal advantages of the process.

Hydrogenation.—A third and perhaps more far-reaching phase of oil refining as a manufacturing industry appears on the scene with the introduction of hydrogenation. The scientific and engineering background of this development is so far reaching as to dwarf all previous experience. Pure chemistry and physics and all branches of engineering have already and in the future must continue to supply the best of which they are capable, if the new development is to realize its full possibilities. The fact that hydrogenation was fathered by the foremost organization of scientists and technologists engaged in industry, the I. G. Farbenindustrie of Germany, and that even with their resources

[9] Day, R. B., The Economic Aspect of Cracking, Petroleum World, April, 1926.

[10] Petroleum Refineries in the United States, January 1, 1929, Bureau of Mines Information Circular 6116.

some five years were spent in what may be called preliminary work and another five years in development participated in by the Standard Oil Company (N. J.), before any attempt was made at commercial operation in the oil industry, provides a fair index of what it involves in the way of technical problems.

It may be fairly asked what was the compelling reason for undertaking such an ambitious and necessarily costly development. The answer is that it was shown that hydrogenation gave a definite solution of all present basic problems of the petroleum industry. In the first instance, hydrogenation effectively and practically converts coal into oil. The world's coal reserves have become the world's oil reserves. Thus for hundreds of years at least the basic problem of an adequate future supply of liquid hydrocarbons seems to be settled. Second, hydrogenation can produce 100 per cent by volume of gasoline from the lowest grade of crude liquid hydrocarbons derived either from coal or from oil. Third, hydrogenation shows many interesting possibilities for other conversion operations by which any desired grade of quality of hydrocarbon product may be obtained without prohibitive cost. It is as yet too early to attempt any strictly commercial analysis of this development. Of its outstanding importance and the gross economic changes which it effects in the petroleum industry there can be no doubt.

It is true that known crude oil reserves are not unlimited, but the most pessimistic estimate which could now be made must place their exhaustion many decades ahead. Hydrogenation makes possible and reasonably economical a gasoline production from crude oil about twice as great as present production, still leaving sufficient margin for the production of other petroleum products of high economic value in the proportions in which they would now appear to be required.

The fundamental principles underlying the hydrogenation process have been reviewed in a previous chapter on coal and only its relation to the oil industry will be pointed out. It is not to be regarded, in its present state, as a competitor of the cracking methods of making gasoline, but will find special application in the treatment of crudes of high asphalt and high sulphur content which could not be satisfactorily handled by cracking. There is thus provided a market for a type of crude oil which forms an increasingly large proportion of the total crude supply, and at the same time provides a scientifically possible method of maintaining a balance between supply and demand of light and heavy products. Furthermore, hydrogenation is found to be adapted to the manufacture of specialty products, such as highly refined lubricating oils and similar expensive products.

In March, 1930, the Standard Oil Company (N. J.) and the I. G.

Farbenindustrie announced the formation of a new company for offering licenses in the United States to oil companies for the use of the catalytic hydrogenation process. This new company will take over from the Standard I. G. Company the rights to the process in this country. The Standard I. G. Company was formed in November, 1929, as a wholly owned subsidiary of the Standard of New Jersey and the I. G. to exploit the process outside of Germany.

The offer here requires that every company licensed shall subscribe to the stock in the new company and shall pay also a small royalty. The licensing offer is open to all refining units in the United States that the Standard Oil Company believes can make commercial use of it. The Standard already has commercial plants for use of the process at Bayway, New Jersey, Baton Rouge, Louisiana, and Baytown, Texas.

Natural Gasoline.[11]—The natural gasoline industry is of interest because of its increasing share in the motor fuel supply. Natural gas-gasoline, sometimes called "casinghead" gasoline, is a highly volatile light oil contained as a vapor in the gas that usually accompanies oil in the pool.

The natural gasoline industry, beginning in 1903 in Pennsylvania, has spread to every important gas and oil field in the country. Natural gas invariably accompanies oil in the strata although not all gas wells contain oil. Natural gas in wells which contain no oil or only a small amount usually does not contain natural gasoline. Where the gas is associated with oil, it becomes more or less saturated with the lightest fractions of the crude oil, that is, the gasoline part of the crude. This type of gas is referred to as wet gas. In the early days of the industry the natural gasoline content of gas was wasted, or, if recovered, was used as fuel in the oil fields. It required years for natural gasoline to find a market among refiners and dispensers of motor fuel to the public. Its value as a blending material and the method of using it were not well understood and, as a result, it was slow in gaining favor.

Gasoline recovered from natural gas is too volatile a product for use as such in motor cars. It is therefore mixed with less volatile fractions to produce a blended motor fuel. Blending can be done at the natural gas plant, or the raw gasoline is shipped to refiners who use it treating the output of the refineries. The increasing demand for gaso-

[11] The reader is referred to the exhaustive treatise on "The Recovery of Gasoline from Natural Gas," American Chemical Society Monograph, by George A. Burrell, 1925. This volume considers the industry from its inception, including in its treatment a discussion of the chemistry of natural gasoline, technology of recovery, transportation, blending, and use. Also, see Oil and Gas Journal, May 23, 1929, Special Natural Gasoline Number.

line is bringing about a tendency to distil more and more of the heavier hydrocarbons into the gasoline fraction, until a product is obtained which will not pass specifications for motor gasoline. This is particularly true with the increase in output of "cracked" motor oil. These gasolines are blended with the highly volatile natural gasoline in order to supply them with the proper proportion of low-boiling constituents.

The use of the air-gas lift in oil production has served to increase the output of natural gas-gasoline. The continuous cycle of dry gas back into the pool, results in a resaturation of the gas underground with gasoline, which is then recovered in the natural gasoline plants.

Natural gas-gasoline plays an important part in the motor fuel supply. It actually produced about 7 per cent of the gasoline used in this country in 1927, and makes available for motor car use, by making it more volatile, a much larger quantity of low-volatile refinery motor gasoline.

CHAPTER XII

ORGANIZATION OF THE OIL INDUSTRY

THE characteristics of the oil industry are in no small measure the outgrowth of the early organization and control by a combination of refiners, the so-called Standard Oil Trust. The present organization within the industry is the outgrowth of a series of events dating back to a decree of dissolution of this combination in 1911. At this time, the relative power and prestige of the Standard Oil Trust was so great, and the methods of dissolving it so gradual in their operation, that the profound nature of the changes which have occurred and are still occurring is not generally understood. The change in control, moreover, is greatly accelerated by the tremendous expansion of the industry and the building up of many new organizations of great size and resources.

In 1906, when the Bureau of Corporations made its report on the Standard Oil Company, this organization was found to control over 80 per cent of the crude consumption, about 85 per cent of the refining, and 88 per cent of the principal product, illuminating oil. The Standard did not have a monopoly of crude-oil production either through ownership or through lease or other contractual control of producing areas. In fact, it deliberately followed a policy of permitting independent producers to cope with the hazards that this branch of the industry incurred. However, this combination of refiners was the only large consumer of crude for refining purposes and the producing areas from which most of the refinable crude was obtained were so situated geographically that it had to be transported considerable distances either by pipe line or by railroad to reach Standard refineries. Pipe-line transportation was very much cheaper than rail transportation. The Standard, by reason of its ownership of practically all the important pipe lines, became not only the purchaser and consumer of the great bulk of the output, but was able to fix its own price for crude at the wells. It thus had nearly as complete a control of the output of crude as it would have through ownership of the producing areas, and without having to incur the highly speculative risks of drilling wells or to carry the investment covering them.

In 1906, the Standard Oil Company of New Jersey controlled, through stock ownership, 10 refining companies, 4 lubricating oil and compounding companies, 3 crude-oil producing companies, 12 pipe-line companies, 1 tank-car company, 6 marketing companies, and 16 natural-gas companies in active operation in the United States, and 15 companies in active operation in foreign countries. In addition to these there were a number of other concerns so closely associated with the Standard by contract and otherwise as to be in large measure controlled by it.

The dissolution decree, issued in 1909, and upheld by the Supreme Court in 1911, did not change the ownership of the Standard interests but made the ownership direct in the stockholders of the Standard of New Jersey instead of indirect through a holding company. Nor did the decree change the control which the Standard interests as a whole had over the industry. However, the change of the ownership of Standard interests from stockholdings in a single company to holdings of stock in many companies with differing possibilities and earning powers was sure in the course of years to disperse this control as individuals found it desirable to dispose of their holdings, or as death necessitated distribution of them, or to dilute it as expansion of the industry required the use of new capital.

Each Standard marketing company, following the practice of the organization before the dissolution, still confined its operations to a specific field bounded by state lines, and only in the case of the Magnolia Petroleum Corporation and the Standard Oil Company of Louisiana did these fields overlap. The Standard Oil of Nebraska was organized to meet legal requirements of that state and operated only within its boundaries. In other cases the extent and location of the territory of a Standard marketing company was determined partly by rates of transportation and partly by the capacity of the refineries serving the company.

Effect of Dissolution Decree.—The controlling ownership of the several Standard Oils at the time the dissolution decree was put in effect rested in three or four individuals. The effect of the dissolution decree has resulted in such a dispersion of stock and breaking up of the former common interests of the Standards that the different units are now practically or largely independent. There are signs also that the exclusive marketing privileges enjoyed by each Standard unit in its own territory is breaking down and that competition between the Standards is taking on the aspects of completely independent companies.

The control of the Standard group over the pipe-line companies is also showing interesting changes. In 1906, the interstate pipe lines were placed under the regulation of the Interstate Commerce Commission and their services made subject to the demand of any shipper of oil who might wish to avail himself of them. At that time the Standard had trunk lines connecting the important refining centers with all producing fields east of the Rocky Mountains except the Gulf. It also had lines connecting the principal California fields with its refinery at San Francisco or with the Seaboard. Its trunk lines to the Atlantic Seaboard terminated at Philadelphia, Baltimore, and the vicinity of New York harbor.

There were then only two pipe lines, other than those of the Standard, that were engaged in interstate transportation of oil. The Pure Oil Company had a line extending from West Virginia and southern Ohio through northern Pennsylvania to the neighborhood of Philadelphia. The Tidewater Pipe Company had a line extending from northern Pennsylvania to tidewater at Bayonne, New Jersey. The tariffs filed with the Interstate Commerce Commission under this act by the Standard lines required a minimum quantity for shipment so large as to preclude the use of these lines by independent refiners in most cases. As a consequence they continued to serve the Standard refineries.

With the great increase in production in the Mid-continent field, conpanies entirely independent of former Standard interests became of greater importance and extended their pipe-line systems to connect that field with Gulf points and refining centers. There are now three large companies quite independent of the influence of any Standard company that have extensive pipe-line systems. These are the Gulf Oil Corporation, the Texas Company, and the Shell Union Oil Corporation. The pipe lines of the Gulf and Texas companies extend from this field to the Gulf and also connect it with refining points in Texas. The Ozark pipe line of the Shell Company connects with St. Louis and Chicago. Besides these, the Sinclair Pipe Line Company and the Sinclair Gulf Pipe Line Company, both owned jointly by the Standard Oil Company of Indiana and the Sinclair Consolidated Oil Company, operate trunk-line systems whose combined lines extend from the Great Lakes to the Gulf and connect the Mid-continent, Texas and Wyoming fields with the refineries at Chicago, Kansas City, and Houston.

Reports received from different refining companies indicate, however, that these pipe lines practically serve only the companies with which they are affiliated. On the other hand, the pipe-line companies which belonged to the old Standard interests have acted as common carriers for all refining companies evolved from the Standard combination, but did not serve other refineries to any great extent until the order of the Interstate Commerce Commission in 1922 directed the Prairie Oil and Gas Company to reduce the minimum that would be accepted for shipment to certain points to 10,000 barrels. Following this order a voluntary reduction in the minimum was made for a number of other points. As a result of this change in policy the deliveries of Mid-continent crude to independent refiners by Standard lines increased from less than one-third of 1 per cent of the total in 1922 to between 15 and 20 per cent of the present (1926).

The following table shows the proportions of the important branches of the oil industry, other than marketing, that are controlled by different large units or groups of closely related companies. The grouping is based on the relation of the companies to one another on June 30, 1926, and the statistics of operations are for the preceding calendar year.

TABLE VII*

DEGREE OF CONTROL OF THE INDUSTRY BY LARGE GROUPS

	Standard Groups,† Per Cent	Standard Associates,‡ Per Cent	Other Large Groups,§ Per Cent	Total of All Groups, Per Cent
Proven acreage	47.4	11.5	7.6	66.5
Crude produced	24.5	4.8	13.9	43.2
Crude consumed	45.8	7.9	14.5	68.2
Gasoline produced	43.1	8.4	15.1	66.2
Kerosene produced	56.0	5.0	13.4	74.4
Fuel oil produced	42.1	8.6	13.1	63.8
Lubrication oils produced	55.5	6.7	13.0	75.2

* From Table 30, p. 77, of the Federal Trade Commission's Report on Prices, Profits, and Competition in the Petroleum Industry, Senate Document 61, 70th Congress, 1st Session, 1928.

† Includes Standard Oil Companies of New Jersey, New York, Indiana, and California, Atlantic Refining Company, Prairie Oil and Gas Company, Continental Oil Company, Vacuum Oil Company, Ohio Oil Company, South Penn Oil Company, Standard Oil Company (Ohio), Standard Oil Company (Kentucky), Galena Signal Oil Company (Pennsylvania), Standard Oil Company (Kansas), Solar Refining Company, Standard Oil Company (Nebraska).

‡ Includes Sinclair Consolidated Oil Corporation, Tidewater-Associated Oil.

§ The Texas Company, Gulf Oil Corporation, Shell-Union Oil Corporation.

The groups covered by this table are arranged in three classes: The units growing directly out of the dissolution proceedings; those which are to some extent associated with one or more of these evolved units; and the very large groups that are entirely independent of any of the units resulting from the dissolution. The purpose of this method of treatment is (1) to call attention to the substantial decrease that has taken place in the proportion of control of certain branches of the industry by the Standard companies in the aggregate and (2) to show the extent to which there is still control over the industry by a few large groups.

While there has been a marked dispersion of control of the refining industry in the period following 1911, there has been quite a strong tendency toward concentration in control of the natural resources. The Standard Oil Company was not especially interested in producing areas before the dissolution, but the evolved units are now among the largest holders of proven acreage, their combined holdings at the end of 1925 being 47.4 per cent of the total of such acreage and practically the same as the combined proportion of refined products. While this acreage is not all in rich producing areas, consolidation since the end of 1925 has brought under the control of particular Standard groups other areas that would substantially raise the average quality of the holdings.

The Competitive Era.—The period since 1911, the date of the dissolution decree of the old Standard group, may be termed the era of dispersion of control, for not only did the action of the Supreme Court loosen the bonds of solidarity among the Standards but during this time new and powerful companies were emerging out of the rapidly growing business. The discovery of prolific areas in the Mid-continent field stimulated the formation of oil companies some of which were badly organized and soon disappeared, other were frauds, while a third group rose to places of varying importance in the industry.

The mounting demands for gasoline enable new refining companies to succeed in the field in the face of competition with the powerful and well-organized Standards. Producers increased in numbers even faster than refiners, enticed by the lure of wealth that was supposed to accompany the discovery and production of oil. There was no attempt to analyze the market needs or possibilities. The goal was more oil. The consequences of this period of rapid growth and expansion of production and refining facilities were recurring periods of overproduction, with its toll of losses, depressed prices, and wastage of crude oil. The producers were usually the greatest sufferers inasmuch as they were virtually unable to control or curtail production. Expansion in the refining branch, however, went on apace and in the overproduction era beginning with the opening of the Seminole pool in 1926 and continuing until 1930, the oil industry experienced a severe depression due to the production of unwieldy surpluses of fuel oil and gasoline, as well as of crude. The conclusions that must be drawn from this state of affairs is that the oil industry as a whole has not as yet evolved the type of organization which is adapted to an economical and efficient handling of the business of producing, refining, and marketing of oil products. The weakest point, as will be seen later, is in the producing branch.

The Rise of Mergers.—The untoward results of wide-open competition in crude oil production and marketing of refined products, together with a desire on the part of refiners to protect their investment with an assured reserve of crude, is bringing about an evolution into what appears to be a third phase of the oil business, i.e., the rise of mergers. The character of these mergers varies from the consolidation of small producing properties to the organization of completely integrated concerns embracing production, transporting, refining, and marketing companies, some of which operate on a world-wide scale.

There is a general feeling that within a few years there will be not more than eight or ten important factors in the oil industry. This does not mean that all the smaller companies are going out of business, for there will always be a large number of these concerns, especially in the marketing branch. The middle group of companies, however, those that are weak in one or more of the branches of the industry will have to expand, consolidate, or probably fail.

The tendency of the oil industry is best illustrated with what has been taking place in the Standard Oil units since the dissolution. With the exception of the Standard Oil Company of California, which was more or less of an integrated unit from the start because it was isolated from the remainder of the Standard Oil units, the companies in this group had to embark on an expansion program. The Standard Oil Company of New Jersey, the parent organization, had little production after the dissolution decree. Since 1921 it has acquired production properties in foreign lands as well as at home, pipe-line facilities, and refineries. Consequently, it is now regarded as a well-integrated unit, but it was weak at the start.

The same is true with the Standard Oil Company of Indiana, although its development into an integrated unit was slower. At the time of the dissolution it had only a small refinery and ten mid-western states in which to market its products. Its first move was the acquisition of the Mid-West Refining Company which gave it some crude production in Wyoming. Its second important step in expansion was the formation with the Sinclair Company of the Sinclair Crude Oil Purchasing Company and the acquisition of a one-half interest in the Sinclair Pipe Line Company. Its next step was the acquisition of a controlling interest in the Pan-American Petroleum and Transport Company, which insured it large crude oil reserves, mainly in foreign countries. Finally, the purchase of the remaining one-half interest in the Sinclair Crude Oil Purchasing Company and the Sinclair Pipe Line Company made it an integrated unit.

The Standard Oil Company of New York has attempted to become an integrated unit in the industry during the past few years with more or less success, although it is not considered as being a thoroughly integrated unit as yet. This company has acquired the Magnolia Petroleum Company, the General Petroleum Corporation on the Pacific Coast, and the White Eagle Oil and Refining Company in the Mid-continent area. In an attempt to further round out its organization, the New York Company attempted to acquire the Vacuum Oil Company, but this is being contested in the Federal Courts by the government as being in violation of the dissolution decree of 1911.

In oil circles it is believed that the Standard of New York and the Vacuum Company are preparing to pool their resources in a test of strength with the Royal Dutch-Shell, not only in foreign countries but also in the United States, where the latter company has been rapidly expanding its operations. Plans for the consolidation of other companies besides the Standard of New York and Vacuum are awaiting the outcome of the court decision.

The Sinclair Consolidated Oil Corporation purchased the Prairie Oil and Gas Company and the Prairie Pipe Line Company, both former Standard Oil units. The activities of these companies are confined almost entirely to the production, purchase, sale and transportation of crude oil. For a number of years the Standard of New Jersey was the principal customer of the Prairie Oil and Gas Company, but through changes in the industry, this connection was severed several years ago. As a result of this and other changes the company was practically forced to consolidate with a refinery and marketing organization or operate at a decided disadvantage.

The Texas Corporation has gradually expanded its operations until now it is a nationwide organization. The Shell Union Oil Corporation, controlled by the Royal Dutch-Shell group, is the only other oil company operating nationally. The aggressiveness of Shell Union has caused considerable concern among some of the major American oil companies. The increasing importance of this company in the petroleum industry of the United States has caused a general feeling that a company must be nationwide in its operations if it desires to be an important factor.

Oil Organization in Foreign Countries.—Thus far the discussion has been limited to the organization of the oil industry within the United States. The international character of the petroleum industry and the world-wide activities of some of the larger oil companies warrant a brief review of both the foreign activities of American companies and the extent of operations of foreign companies.

Outstanding among the American companies having foreign interests is the Standard Oil Company of New Jersey. Through subsidiary and affiliated companies, this organization now produces in Venezuela through the Creole Oil Company, and has a controlling interest in the Humble Oil and Refining and the Imperial Oil Companies. While remaining essentially a petroleum company, it is rapidly building up a chemical division after an alliance with the I. G. Farbenindustrie, the German dye trust. At the same time it has continued to expand its natural gas business, so that the company is an important public utility enterprise. The company produces and markets a number of chemical and drug specialties from petroleum. It has a 50 per cent interest in the Ethyl Gasoline Company, the other half being owned by the General Motors Corporation. The most interesting development, in 1929, was the projection of methods of producing and refining oils by catalytic hydrogenation. This development was carried on under a contract with the I. G. Farbenindustrie that gives the New Jersey company rights to patents on various of the former organization's processes. Through the hydrogenation process, it is possible to extract increased percentages of gasoline and other "white" products from crudes of high asphalt and sulphur contents which now constitute a large proportion of refinery supplies.

The Standard of New Jersey owns abundant raw materials, has a transportation system that is the largest pipe-line network in the world, and operates an extensive fleet of ocean-going vessels. Also, its refineries are rated as the most extensive in the world. The New Jersey company has the largest distributing organization in the country.

Of the foreign companies, most famous is the organization known as the Royal Dutch-Shell group, a British-Dutch combine operating in many countries throughout the world. The company had its origin in a union, in 1907, of the Royal-Dutch Company, formed in 1890 for the purpose of exploiting oil lands in the Netherlands East Indies, and the Shell Trading and Transport Company, a British concern. The resulting combine, the Royal Dutch-Shell became a holding company with 60 per cent of the stock belonging to the old Dutch Organization.

The extraordinary ramifications of the Royal Dutch-Shell group may be judged from the list of subsidiary companies under its control numbering over a hundred, located in various parts of the world and engaged in producing, transporting, refining, jobbing, and marketing of oil and its products. As early as 1921 this group, in addition to its possessions in the Dutch East Indies, owned exclusive or important petroleum properties in Sarawak (British Borneo), Rumania, Egypt, Venezuela, Trinidad, Mexico, and the United States; and it controls refineries in the United States, Mexico, Venezuela, Trinidad, Curaçao, Suez, and others in Europe and the Orient, together with compression plants, storage facilities, and other equipment in different parts of the world.

It has extensive pipe lines in the United States and in Mexico. It also owns or controls tankers, barges, and tugboats.

The Royal Dutch-Shell group operates about 120 fuel-oil bunkering stations, 10 of which are in the United States. Oil bunkering stations operated by this group are located at all important seaports throughout the world. For example a British steamer leaving New York City on a voyage around the world calling at every important port in Europe, along the Mediterranean, in India, the East Indies, China, Japan, the Philippines, Australia, New Zealand, and the west coast of North America, and then returning to New York City through the Panama Canal, would find oil bunkering stations operated by a member of the Royal Dutch-Shell group at every important port of call.

Through the acquisition of the assets of the Union Oil Company and merging practically all of its American operations under this newly organized corporation, the Royal Dutch-Shell holdings rank among the largest in the petroleum industry of the United States.

This combine, with its remarkable ramifications and world-wide activities, is one of the most outstanding cases of world industrial organization.[2]

The dominance of the American and Royal Dutch-Shell groups in the oil business must not be permitted to obscure entirely the activities of other groups of companies, particularly in Russia and the Anglo-Persian Oil Company. The latter has an interesting history growing out of the exigencies of the World War. As late as 1913 less than 2 per cent of the world's oil output was on British territory and the greater part of this was produced by the Burmah Oil Company operating in Burma and Assam. In 1909 the Burmah merged with the First Exploitation Company, a British concern operating in Persia under exceptionally favorable conditions, to form the Anglo-Persian Oil Company. Although possessing rich oil fields and exceptionally favorable conditions of production, the scale of operations was modest compared with the principals in the oil industry. The outbreak of the World War was accompanied by an unprecedented demand for raw materials, including oil. The Anglo-Persian Oil Company, unable to meet British needs for oil without expanding its capital equipment, accepted £2,200,000 from the British government, which then gained a controlling interest in the company. Although a war-time measure, the investment has proven to be profitable to the British Government, and since the war, this company has been operating as a government-owned industry.

In contrast to the organization of the oil industry under American,

[1] Report of the Federal Trade Commission on Foreign Ownership in the Petroleum Industry, February 12, 1923.

British and Dutch control, the *Russian* oil industry is not supported by a powerful group or concern. The troubled political condition of Russia since the war has been an obstacle to private exploitation of oil. The moderation of the national policy has been accompanied by rumors of Soviet oil concessions to foreign groups, including interests in the United States, but this is still unverified.

The Russian oil industry assumes a world-wide interest because of its competition with the American and British companies in the European and Asiatic market. The political angle of the relations of Russian oil to the world, arising out of the controversy between the Royal Dutch-Shell and the Standard of New York in 1927, served to obscure the economic factors of the situation. The logical outlet for Russian oil products outside Russia is the territory embracing south central Europe and the Near East. Russia can reach these markets in competition with all other fields and can logically undersell its competitors. The decision of the Standard Oil Company of New York and the Vacuum Oil Company to handle the Russian oil products in these districts merely resulted in a transfer of the marketing end of the Russian oil business from Russian to other interests, and did not involve the entrance of Russian oil into this territory for the first time, as many have supposed.

The decision of the American companies to purchase Russian oil was based on the fact that Russia was bound to compete in these markets at any rate and also on the fact that from an economic viewpoint the contracts were sound. The Royal Dutch-Shell Company is in a different situation in the Near East and India from the Standard Oil of New York and the Vacuum Oil Company. It has production in Rumania and the Dutch East Indies and can supply the Near East and Far East from these fields at prices below those at which American oil is delivered. Hence its opposition to the negotiations of the American oil companies with the Russian producers, ostensibly based upon political reasons, had an underlying economic interest.

CHAPTER XIII

THE ECONOMIC PROBLEMS OF THE OIL INDUSTRY

THE growth of the petroleum industry and of the demand for the products obtained from oil has left in its wake a series of perplexing economic conditions which have not been satisfactorily solved and disposed of as fast as the ever-changing conditions of the oil industry bring them forth. These problems, though ramifying the entire structure of the organized oil industry, has been most acute in the production branch. Complaint is made of waste in production through certain methods employed; through overdrilling; through the inducement of those having properties within a newly discovered oil field to rush at once to the production of all the oil that can be got out, with the consequence, it is strongly urged, of waste in the process of production by the exhaustion of the gas, and of waste through overproduction by the encouragement of uneconomical uses. It has been strongly emphasized that substantial waste occurs when oil pools are excessively drilled. It is pointed out that wells are drilled on very small tracts of land, near their boundary lines, and that this in turn necessitates offset drilling by adjoining land owners to protect themselves against damage, which applies to each successive ownership in turn throughout the area. It is said that frequently ten or more wells are drilled within a space where good practice would warrant but one. It is emphasized that such drilling results in a very rapid development, meaning at times sudden large production, a flooding of the market, so that in addition to the drilling there are other losses. Again, by the ordinary methods of flowing and pumping a very large proportion of petroleum is left in the ground. The amount is variously estimated; some maintain that four or five barrels of oil are left in the ground for every barrel recovered by flowing or pumping, and others insist that what is left in the ground constitutes a still larger proportion. It is also urged that to a great extent the natural gas has been wasted through present methods of production.

The producing branch of the oil industry needs reorganization. The ills attending production are concerned (1) with wastes, physical and financial, (2) with uncontrolled and excessive output of crude oil, and (3) with rapid exploitation of a valuable resource whose duration of life is uncertain. A practical and workable policy for the sane and orderly utilization of the country's heritage of oil must be formulated. A wisely formulated policy necessitates a study of the conditions existing under which oil is now being produced. We began with a study of wastes in oil production.

Wastes of Production.—Among these wastes, a serious and tragic one is that of natural gas. The waste of this resource occasions losses in several ways. There is, first of all, an escape of a valuable fuel, superior to manufactured gas, an ideal fuel for domestic heating and many industrial uses; and, once lost, absolutely irrecoverable. Secondly, the premature escape of gas from oil wells affects the degree of recovery of oil from the underground reservoirs. "It is generally admitted that the present commonly used methods of production are securing less than 25 per cent of the oil that is actually present in the reservoir sands. Some authorities have placed the extraction as low as 10 per cent or 15 per cent in certain fields. Natural gas in the oil sands becomes the most important agent for increasing recovery of oil. In some fields water is the all-important expulsive force and in some gravity assists in production, but in most fields water and gravity are of minor importance when compared to the work of gas.

Gas in an oil sand should be looked on primarily as a source of energy rather than as a substance. This stored energy is the prime motive force for the extraction of the oil from the reservoir. It drives the oil through the minute pore spaces of the reservoir rock to the well and lifts or helps to lift it to the surface.

Gas has a second and almost equally important value—its value in increasing the fluidity of the oil. Part of the gas in an oil sand may be in liquid form; part may be dissolved in the oil. The amount that may be dissolved depends upon the character of the oil and the character of the gas and is proportional to the temperature and pressure.

The greater the amount of dissolved and liquid gas in an oil the lighter the oil, the less viscous, and the lower the surface tension. Specific gravity, viscosity, and surface tension of the oil are all lessened by the solution of the gas, and as these are lessened the mobility of the oil is increased. Rendered more fluid by the gas, the oil can pass through the intricate, tortuous interstices of the reservoir and find its way to the area of lower pressure at the well. Greater fluidity, greater mobility, greater ease of movement—these represent the solution value of gas in oil.

When a well penetrates a petroleum reservoir, theretofore untouched gas pressure is released about the well and oil and gas begin to flow through the reservoir spaces toward the point of lowered pressure. As the fluid moves toward the well there is a progressive drop in pressure. With the drop in pressure the free gas expands and drives the oil through the sand; the dissolved gas comes out of solution and becomes free gas; the liquefied gas vaporizes and also becomes a free gas; and the additional free gas also helps to drive the oil to the well. The progressive liberation of energy increases the velocity of the fluids and overcomes friction as they move through the rock voids toward the point of egress. If the pressure is too rapidly reduced permitting excessive escape of gas from the well, the proportion of oil left in the reservoir is increased. The problem of the producer, then, is to so regulate the gas-oil ratio that will result in the maximum recovery of oil by the pressure within the pool. The most effective gas-oil ratio[1] can be determined only empirically and by a study of results of trials in other pools. No doubt, it will vary for different pools and at different stages in the exploitation of the same pool. Moreover, gas-pressure utilization will be inefficient if there is no coordination among the operators having wells within the same pool. Waste of gas energy can result from sinking wells in a pool at different times or from using different gas-oil ratios at each of the wells. The success of pressure control as an aid to improved production practices depends upon cooperation among producers in the exploitation of a pool. The problems involved and the obstacles to be overcome in bringing the producers together will be discussed under constructive oil policies.

Some believe that the remaining 75 per cent or more is not lost but may be recovered in the future by more efficient processes yet to be developed. While it is true that processes are known—such as water flooding and the application of compressed air or gas to the sands—which may be applied when the lower limit of production by flowing and pumping is reached, there is no assurance that such processes are of universal application. Furthermore, present-day operations are often conducted in a way that leaves the productive sands flooded with water or sealed with solidified asphalt of wax, so that the remaining oil will probably not be producible by any known process of recovery. This loss is probably the most serious one with which the oil industry may be charged, the more serious because it is largely remediable through the use of methods of recovery by controlled gas pressure already known to the industry, but not used because the highly competitive system of production of to-day does not permit the production of anything but the cheapest oil, necessitating the use of methods which give little regard to ultimate recovery.

[1] Gas-oil ratio: the number of cubic feet of gas produced per barrel of oil from a well.

Turning next to the capital losses which result under the present system of petroleum production, we are again confronted with conditions which are productive of serious economic waste.

One of the most serious of these capital wastes in oil production is that which results from overdrilling and improper spacing of wells. The industry has not yet developed a method of determining the economic spacing of wells. Practice in spacing and arrangement of wells varies widely, and in most cases, their locations are determined by property boundaries and competitive conditions rather than by the principles of drainage and economics.

In almost any oil field in the United States, important capital losses due to lack of economy in well spacing, may be demonstrated, but in the so-called "town-lot" fields, in which land is held in small tracts, the situation is particularly aggravated.

The high cost of ill-advised drilling is accompanied by uneconomic expenditures for facilities to handle the sharp but short-lived peak loads of oil production. Pipe lines are hastily built only to be used for a short time; expensive storage facilities are erected; irregular labor conditions are promoted. Harmful social conditions result.

Effect of Leasing System.—The high cost of excessive drilling can be laid to the legal concepts of property in oil and the leasing system which is built around it. The right of the surface owner to mine the minerals below the surface has never been questioned in the United States. It is one of the basic principles of our legal system and is given much credit as a factor of major importance in the development of natural resources. The sub-surface ownership of mineral rights by the surface owners was due solely to the fact that the United States has inherited the English system of rights and, throughout the early development of this country, no condition arose to cause Congress to see the necessity of change.

Both the English and American laws uphold the right and prescribe heavy penalties for the miner who is found guilty of extracting solid minerals from below the property of a neighbor without his consent. It would appear that this same law would apply to oil and gas resources, giving the owner or lessee the right to prevent an adjacent owner, who desired to drill and produce wells, from draining oil from below his property. Nevertheless, that a modification of this principle has occurred, in regard to oil and gas, is recognized by all oil producers. The character of this modification is clearly indicated by the words of a Pennsylvania judge in giving a decision in a case involving the ownership of gas in 1889: "Possession of the land, therefore, is not necessarily possession of the gas. If an adjoining, or even distant, owner drills on his land and taps your gas, so that it comes into his well and under his control, it is no longer yours, but his." This was merely giving voice to an opinion commonly held among Pennsylvania oil men at that time. From the beginning, the oil and gas industries of the United States have built their practices upon this principle that ownership of the surface gives the right to drill and to produce as the owner sees fit even if oil and gas are drawn from other properties. The owner of the surface may be defined as the owner of the right to produce any oil or gas that may come into his wells.[2]

The fact that the owner of oil land has only a theoretical property right in the oil beneath the surface, and can realize on that right only to the extent that he recovers the oil through wells on his land before adjoining owners can capture it through wells on their land, introduces a competitive element in the production of petroleum which exists in no other industry. This characteristic of property in oil is responsible for developing the present leasing system.

Under the ordinary terms of the usual type of oil and gas leases, the lessor is compelled to protect his lease holdings by starting drilling immediately after any wells are drilled in the sand offsetting the property. This clause, which was originally intended to protect the various landowners against the dangers of property drainage, has done much to promote the unusually expansive drilling activity witnessed in the Greater Seminole area of Oklahoma, in 1926 and 1927. It could cause a similar economic disaster in any portion of the Mid-continent field, for in almost every region of that territory, the same leasing conditions exist. The lease forms used for taking oil and gas leases in the Mid-continent field either contain, or have implied, a clause which provides for the starting of wells to protect the property from drainage by offset wells. To quote one form:

> Lessee agrees to immediately offset all paying oil or gas wells drilled on land adjoining this tract, and it is expressly agreed that no implied covenants regarding the measure of diligence to be exercised by the lessee in the drilling of said land during the original five-year term hereof shall be read into this lease, it being the express agreement of the parties that the provisions of this paragraph set forth the exclusive conditions under which the lessee shall hold this lease for said original term of five years.

If a property is divided into many small holdings or leases the conditions favoring overproduction are further increased. In the Seminole area, for instance, a few 10-acre leases did more to upset the carefully

[2] Readers interested in the legal principles governing the extraction of oil and gas, and the proper conservation of these commodities should consult the able paper of Mr. James A. Veasey in Vol. 52 of the Reports of the American Bar Association, p. 577.

laid plans than any of the numerous contributory causes which led to the mad rush to drill in this field.

During the fall of 1926 the Searight and Seminole pools were producing, and one Wilcox sand in the Earlsboro sector had been completed. On the south edge of the Seminole city pool, the fatal 10-acre tracts were located; and when wells were completed offsetting their lines, the owners of these leases were naturally compelled to start drilling. The very porous nature of the Wilcox formation in this field is thought to have permitted the effects of drainage to exert wider influence than in the majority of operations, and the fear that drainage would affect the leases a quarter or even half a mile from the lines of the small leases led to an insistence upon the part of the royalty owners that the leases near producing properties be started immediately.

It has been estimated that over 90 wells were started as a result of small acreage tracts. The average lease in the Seminole area contained 40 acres. Many 80-acre tracts were in the field, and a few tracts containing 160 acres. Had the parcels of land been larger, the fear of drainage would have been lessened due to the wider spread of leased land, and much unnecessary drilling would have been eliminated.

The forced overproduction of oil brought about by the lease system in vogue compels inefficient methods of drilling and recovery when the industry has available knowledge of better methods. The escape of gas, and ill-advised methods of drilling together conspire to bring about the low recovery of crude already mentioned. There is ample evidence indicating that if the gas associated with the petroleum in our oil fields were conserved and elevated gas pressure maintained in the oil sands during their productive life, the ultimate production of petroleum could be greatly increased. It seems probable that we could increase the percentage of ultimate recovery and greatly extend the radius of drainage of wells if we were to drill them of larger diameter or excavate cavities about them within the oil sands.

Much of the oil left in the sands as unrecoverable by present-day methods, is lost through lack of uniformity in field development programs of competing producers. For maximum recovery, timely drilling of all areas within gas-drainage radius of each other is essential. The early wells in a new field are usually far more productive than later-drilled wells, because they have the advantage of higher gas pressure. They secure the production, however, only at the expense of gas from oil beyond oil-drainage radius, thus leaving undrilled areas in their vicinity gas drained, so that later-drilled wells in these areas recover only a fraction of what they might have secured if drilled before gas drainage occurred.

Data gathered some years ago in connection with a study of the California naval reserves, indicated that delay of only a few months in the drilling of locations within gas-drainage radius of earlier-drilled wells, means in many cases, a loss of upwards of 50 per cent of the potential production. Delay of a year or two often reduces the ultimate production to as little as 25 per cent of what it might have been with timely drilling. These losses are entirely due to gas drainage, the oil being deprived of its gas and left in the sands without motivating force to bring it into the wells.

In the scramble for early flush production from the deeper zone in the Santa Fe Springs field, Calif., two upper zones were only partially depleted, but gas pressures were promptly dissipated and the upper sands are now said to be flooded in many localities. Had the three oil zones in this field been drained one at a time, beginning with the uppermost, and if gas pressure has been preserved by proper gas conservation, it is probable that this field would have produced at least twice as much oil as it is likely to yield by present methods.

Important underground losses of petroleum also result through failure to adopt a uniform policy of water exclusion and a proper system of control of edgewater encroachment. Many wells are prematurely flooded before they have had time to secure the oil which they might otherwise produce. Much oil is lost in leases of slow-draining, fine-grained oil sand that becomes inundated by encroachment of water through surrounding coarser sand channels. The only remedy would seem to lie in closer study of subsurface conditions and in the adoption of uniform methods of water exclusion and well control.

Many other minor causes of economic loss in the oil industry might be mentioned; evaporation and seepage losses, inefficiency of power development, fire losses, accident losses, losses incurred by failure to provide storage for oil produced in excess of market needs, and interest losses on oil prematurely produced—all important of economic waste, in that they are, at least in part, preventable losses.

Overproduction.—Closely linked with the wasteful practices in oil recovery is the phenomenon of overproduction. Excessive production of oil is accompanied by drops in the price of crude and refined products, wiping out of profits, and the sustaining of losses by operators and refiners.

The crisis of late 1926 is not altogether the result of the unparalleled production of Seminole, for the producing industry had long been approaching a condition that made the industry incapable of digesting the oil from Seminole. The close of the war saw a rapidly expanding automobile industry and a depleted condition of crude oil stocks. Oil production rose to meet the anticipated demand and reserves of stocks increased. In the years 1919 to 1921, oil was obtained from moderately sized pools, no spectacular production being recorded. Consumption of oil was keeping pace with production. The collapse of oil prices in 1921 was due, not so much to overproduction, as to an unprecedented business depression.

Then came a series of pools in the Mid-continent and California fields that with a few exceptions exceeded all production records of the past. (See page 103.)

In addition to the yield from several unusually large pools, overproduction of crude petroleum is brought about by the nature of the crude-petroleum producing industry. Unlike most other minerals, the quantity of crude petroleum in reserve cannot be accurately estimated. Coal, iron, copper, and some other minerals usually occur in masses the contents of which can often be quite accurately estimated by test borings. Crude petroleum, on the contrary, is found in pools the contents of which are not easily measured. Estimates of the quantity of crude petroleum in reserve made in the past by able geologists have all proven to be low, even for developed oil pools; and the numerous periodical predictions of an immediate shortage of crude petroleum invariably have proven wrong.

The uncertainty of the quantity of future production stimulates drilling activity even when prices are stationary or declining. Every producer is familiar with the fact that the initial flow of well and the flush production of an oil pool or an oil field may decline quickly and that it is almost invariably much greater than its settled output. Consequently, the production of the country can be maintained only through an incessant drilling program. These factors conspired to bring to the surface a vast flood of oil without regard to the market requirements.

In connection with the discussion of overproduction, a consideration of the flush pools is necessary in order to understand the economic significance of flush-pool production. It must not be inferred from previous analysis, that these pools are a bane to the industry altogether. Their importance toward meeting the ever-growing demand for oil is evident by the contribution of outstanding pools to the total oil supply. Table VI (page 103) gives accrued production of 24 large pools up to January 1, 1928. The yield of oil from these pools was 4,785,646,803 barrels or 46 per cent of the total production for the country since the inception of the oil industry from 1857 to the close of 1927.[3] The average per well, where available, is an indication of the economic significance of the flush pool in the supply of cheap oil.

[3] Total United States production, 1857 to 1927, was 10,341,675,000 barrels, Report III of the Federal Oil Conservation Board, February 5, 1929, p. 53.

The need of constant drilling and continued discovery of flush pools is shown by the rapid decline which follows discovery and peak production.

To offset the rapid decline of an individual well or pool, a constant drilling program must be maintained. The number of wells drilled each year is constantly increasing. In 1928, 22,331 wells were drilled equal to 9 per cent of the producing wells of the country. Of the wells drilled each year, nearly 30 per cent are dry or gassers. Cessation of drilling operations would be followed very quickly by a serious shortage in the crude oil supply.[4]

The economic consequences of irregular production accompanied by periods of flush production are falling prices and increasing stocks of crude in storage. While there has been a steady increase in consumption, domestic production of crude and imports together created a surplus which has risen almost steadily from 193 million barrels in 1919 to 534 million barrels in 1929. Heavy additions to the stocks of crude occurred in the flush production period of 1927 to 1930. Moreover, during much of this period there have been large quantities of gasoline, kerosene, gas, and fuel oil also held in storage.

The concomitant of excessive production and accumulation of stocks —a drop in the price of oil—affects the oil industry in several directions. While the oil industry has thereby been enabled to supply oil cheaply to the public, the effect on the industry as a whole has not been propitious. In such cases the small operator is likely to suffer heavily. The full effect of the demoralizing price drop of 1927, for example, fell most heavily upon the owners of old wells which constitute 76 per cent of the wells in the country with a combined production averaging less than a barrel per well per day. Yet it is upon these old wells that the country depends for its assured supply of oil. Flush production is soon gone, leaving the settled and declining wells to maintain the output needed.

It is, of course, necessary to carry certain quantities of oil in storage. If kept within proper limits such a reserve serves to stabilize the market. However, the maintenance of price levels by this means does not prevent wildcatters from pursuing their activities. If these do not succeed and new pools are not discovered, the increased price of oil may have justified the costs of storage. If, as in 1927 and 1929, prolific new pools are discovered, thus bringing a fresh supply of low-cost crude on the market, the selling of the oil in storage must be postponed indefinitely if a profit is to be made. Yet with every postponement the chance of

[4] Classification of well completions, Oil and Gas Jour., Vol. 27, March 14, 1929, p. 132; lists production by states and years, 1920 to 1928 inclusive.

making a profit becomes less because of the steadily mounting carrying charges. Sooner or later oil which has been withheld from the market must be sold regardless of whether the sale is made at a profit or not.

Instead of being permitted to function as a real reserve to iron out the seasonal inequalities of production and consumption, excessive surplus of oil indirectly contributes toward intensifying an already aggravated situation.[5]

Stabilization of production, and with it, the inauguration of production methods which will wipe out the wastefulness of resources, capital, and recurring hardships to the large body of small producers, is the urgent problem of the oil industry.

Overproduction and Technology.—Significant among the factors contributing to the overproduction phenomenon are the improvements in both production and refinery technology. Advances in geological and geophysical prospecting have added enormously to the underground reserves in sight. In fact, the extension of the proven reserves was an important factor in the decision of one important refining organization, the Standard of New Jersey, to embark upon a policy of reducing its reserve stocks on hand above ground. The immediate outcome of this policy was a cut in the price of crude in 1929 and early 1930. The air-gas lift, flooding, repressuring, and improvements in the recovery of natural gasoline add their share toward increased oil flow. The application of engineering principles to drilling programs serves to reduce waste and adds to the oil recovery.

The greatest upsets, however, in the balance of supply and demand must be laid to the rapidly changing aspects of refinery technology. The principles of cracking and the new hydrogenation process have been discussed elsewhere. It remains to show how the commercial application of these principles in the refinery have altered the position of the crude-producing industry. Briefly, the cracking process, vastly improved since Burton's discovery, now substantially increases the gasoline recoverable from heavy crudes. This, however, is only part of the story. The same process can be applied to the cracking of the fuel oil residue remaining after the straight-run gasoline has been removed. Thus the potential supplies of raw material available for the manufacture of gasoline are vastly increased by adding fuel oil to the quantity of crude. This condition was particularly aggravated in the period immediately following 1927 when the straight-run refineries of California

[5] Teagle, W. C., The New Basis of Crude Oil Values as Effected by Cracking Fuel Oil, Federal Oil Conservation Board, February 10, 11, 1926; Osborn, C., and Deegan, C. J., The Economic Position of Fuel Oil, Universal Oil Products Company, Chicago.

were throwing large quantities of fuel oil on the market in addition to their large output of gasoline. In fact, a large portion of the distress in the opening of 1930 was due to the piling up on the eastern seaboard of a vast over-supply of gasoline, with a resultant weakness in the entire market for refined products. The oversupply came to a large extent from immense shipments of gasoline from California to the eastern seaboard through the Panama Canal, due, of course, to the fact that California was producing far more oil than the western Coast areas could consume or export to the Orient.

It is evident from the prolific output of 1929, the highest on record, that the producers of crude did not take into account the changes in refinery practice in estimating the market for their output.[6]

Foreign Oil and Overproduction.—The producers of oil, particularly in the Mid-continent field, when faced with the possibilities of compulsory curtailment, were quick to blame the importers of foreign crude on the Atlantic Seaboard for the dilemma of excess oil. Vigorous, but unsuccessful, efforts were made by this group to secure a duty upon oil in the Hawley-Smoot tariff bill. The emphatic statements that foreign imports were ruining the domestic industry should not be permitted, however, to obscure the economic factors involved. If foreign competition is the key to the woes of the oil business then the problem is indeed simple. A tariff on oil would be justified. If foreign oil, however, is not the key to the situation, but is merely one of the component factors in a much broader complex, then it is quite possible that more harm than good to the oil industry may ensue from a policy of a protective tariff.

The temporary relief obtained from a duty on oil would probably be wiped out in a short time by a stimulus to production at home. It must be borne in mind that, in spite of strenuous efforts on the part of the oil industry and governmental authority, i.e., the State of California through its gas conservation law, to curtail oil output, there are abundant underground reserves in sight, and much shut-in production, which could hardly be restrained at the slightest suggestion of a profit.

Neither should the public be stampeded into the belief that a rising tide of foreign oil is sweeping into the country. From Table VIII, the striking fact to be noted is the remarkable constancy of net imports since 1922.

[6] Day, R. B., The Economic Aspects of Cracking, Petroleum World, April, 1926; Egloff, G., Cracking Process Aids Industry, Oil News, April 5, 1923; Osborn, C., and Deegan, C. J., Universal Oil Products Company, Chicago; Teagle, W. C., The New Basis of Crude Oil Values as Effected by Cracking Fuel Oil, Federal Oil Conservation Board, Hearings, February 10, 11, 1926.

TABLE VIII *

FOREIGN TRADE IN OIL

(Thousands of Barrels)

Year	Imports	Exports	Net Imports
1918	37,736	5,884	21,852
1919	52,821	6,253	46,568
1920	106,175	8,583	97,592
1921	125,364	9,552	115,812
1922	130,255	10,637	119,618
1923	82,015	17,210	64,805
1924	77,776	17,871	59,905
1925	61,824	13,127	48,697
1926	60,382	15,356	45,026
1927	58,382	15,843	42,539
1928	79,582	18,962	60,620
1929	78,900	25,775	53,125

* Oil and Gas Journal, February 13, 1930, p. 41.

The flood apparently subsided in 1922 with the decline of production in Mexico. Since that time the rise of Venezuela and Colombia have been counterbalanced by the decline in the former country. Crude prospects for the immediate future indicate a stationary output from the South American countries and a continued decline in Mexico.

A further study of the international movement in oil shows that the United States enjoys a considerable foreign market for gasoline and other refined products. Trends in one of these products, gasoline, after deducting imports of this commodity and also the gasoline equivalent contained in imported crude shows an unmistakable upward movement.

The first effect of the tariff on crude oil would be to divert a large part of the foreign oil to the markets enjoyed by our exporters of gasoline. The apparent advantage to the crude producers by cessation of imports would be met by a corresponding decrease in business for the refiners. This decreased business would in turn react to the ultimate disadvantage of the producers.

The economic salvation of the oil industry will not be achieved through tampering with the foreign end of the business. On the contrary the industry appears to be facing a period during which foreign oil imports will be stabilized. An excellent opportunity is thus presented to Mid-continent and California operators for curtailment of production to wipe out the excess gasoline stocks. Rigorous curtailment can be practiced in the United States without fear that in the meanwhile the foreign producers will nullify the effect by corresponding increases in output.

Government Leases and Overproduction.—The Federal Government is still the owner of vast areas embracing several hundred million acres of land, the title of which is held really in trust for the public generally. Within these areas are proven oil fields and also much unexploited territory holding, in varying degrees, promise of oil in commercial quantities. All of these areas, except some special reserves, were wide open to private appropriation through lease or otherwise, until on March 12, 1929, President Hoover withdrew from entering and leasing the oil lands under public control. Previous to this change in policy, the government leases and permits to drill required the lessee or permittee to start a well in one or two years, even on absolutely wildcat acreage far removed from a market and regardless of general oil market conditions. The great Burbank field, which was developed mainly during the overproduction period of 1923, was leased under these conditions. The result of this policy, in 1927, when the country was producing probably 300,000 barrels daily in excess of requirements and West Texas was threatening to increase this excess production, the government was adding 10 per cent to the year's total production.

CONSERVATIONAL TENDENCIES

Accomplishments.—Losses in the oil industry have been checkmated by attempts at improvement both in the production and handling of oil. The gross forms of waste, such as were prevalent in the early days of the oil industry, have disappeared. Curtailment has been effective during unusually severe crises. Rejuvenation methods are being undertaken. The outstanding conservational measures will be briefly discussed.

Improved Production Practices.—Drilling methods have improved to such an extent that the driller can ascertain the conditions at the bottom of the hole and in formations through which he is drilling or intends to drill and can make preparations accordingly. When possible producing formations are approached, the formation is cored, that is a sample of the formation is cut out by devices known as core barrels, and this sample is examined by the driller or production engineer to determine the presence of oil or gas. If the existence of a gusher is suspected, the producing formation is pierced with a small hole so as to prevent a "blowout." While this is being done at the bottom of the hole, other precautions are taken at the surface. High-pressure control heads are placed on top of the casing and master gates are placed on the casing under the control heads. These may be closed, entirely shutting in the well until provision is made for handling the oil or gas found.

The precautions to prevent waste are continued when the oil is placed in storage tanks. Improvements in the design of these tanks have greatly reduced evaporation. Whereas several years ago, evaporation losses averaged 6.5 per cent from the well to the refinery and 2.1 per cent in the refinery or a total loss of 8.6 per cent, installation of improved methods, including vapor-tight tanks and other devices, proper painting, etc., the petroleum industry has cut this loss 50 per cent during the past few years.[7]

Curtailment and Proration.—A crisis in the petroleum industry in 1927 brought about by overproduction "in a form so malignant as to seem to be without precedent" resulted in a movement for production curtailment with the hope of preventing utter demoralization of prices. The first restriction agreement of major importance was inaugurated in the famous Seminole field, in Oklahoma. The plan in this area provided for restricted output of existing wells, prohibition of drilling into deeper sands, shutting in of production, and a ban on the use of nitroglycerin. The adoption of the plan was immediately followed by a decline.

Pinching in Seminole production by 50,000 barrels daily did not, of course, have any immediate effects on relieving the overproduction situation. The really important feature of the agreement was the fact that it marked probably the first time in the petroleum industry when so many operators with different interests could get together and agree to one definite plan of action. When it is considered, the interests of many of the companies are entirely different; that some companies had a large production and others were not so fortunate; that certain companies had acreage which became practically proven territory by developments; that others had drilled up to most of their holdings; that some companies needed production from their leases for their refinery requirements and others because of contracts—when these things are considered, the fact that all the operators did agree to the one plan marks a step forward in matters so vital to the prosperity of the industry.

Curtailment of production in Seminole was followed by similar action in Yates and Hendricks pools in West Texas, and in Kettleman Hills, California. The curtailment efforts were singularly successful in Yates field, Pecos County, Texas. By agreement among the operators and under the supervision of the Texas Railroad Commission, an

[7] Oil and Gas Journal, December 1, 1927, p. 155.

aggregate potential output of several million barrels daily was kept down to 100,000 barrels. If it had been permitted to develop unrestrained, costs of production, storage, and transportation would have been multiplied many times, as well as intensifying the demoralized condition of the crude oil market.

The discovery of prolific deep sands in California, however, more than offset the effect of curtailment so that production in the early part of 1929 rose rapidly and was not brought under control until the voluntary curtailment agreements of the Oklahoma and California producers in October of that year.

In this connection it should be observed that operators are hesitant to apply curtailment measures during periods of overproduction even though the leases are controlled by a small number of operators and the current prices of oil would make it appear desirable. The experienced operators know that overproduction recurs at frequent intervals and is sometimes of long duration, and he who postpones production in order to secure the benefits of permanently higher prices may have many years to wait. The cost of a fully drilled and equipped lease represents a very substantial investment, and, after money has been spent by an operator in development, it cannot be recovered until the oil is produced and sold. It is evident, therefore, that, even though an operator is in absolute control of a given pool, he cannot shut down production in that pool for a long period without loss to himself.

Rejuvenation of Depleted Fields.—The recovery of but a fraction of the oil in sand has received mention elsewhere. The industry has not been unaware of the existence of this unrecovered oil and the opportunity of devising methods of its recovery. Here is, in fact, a vast reserve of oil awaiting the ingenuity of man to make it available. From the porous rocks in which it is held like water in a sponge, the natural force has been depleted, and the remaining oil lies dormant in the rock for want of an expelling agent. In the past, the oil man has tacitly assumed that the declining yield of his wells meant the exhaustion of the oil itself, whereas we now know that it is not the oil that is exhausted, but only the natural gas which was the principal agent for forcing the oil out of the sand and into the well. Between the wells, some four to nine times as much oil remains as has been pumped to the surface. Nature provided only enough gas to expel a minor part of the oil and artificial forces must now be applied to extract the remainder.[8]

[8] Lewis, J. O., The Rejuvenation of Depleted Fields, Federal Oil Conservation Board, Complete Record of Public Hearings, Feb. 10 and 11, 1926, pp. 49–65, a discussion of the evidences of low recovery of oil and of the methods of obtaining a more complete recovery.

To recover the oil left underground it is first necessary to loosen the hold of the oil on the fine pores in the sand and then to force the loosened oil into the well or gallery from which it can be brought to the surface. Air, gas, water, and the pull of gravity all act both as loosening agents and carrying agents, but by itself none of them will completely remove the oil even under the most favorable conditions. To gain very high recoveries it will be necessary to supplement these carrying agents with some additional agent that will reduce the tendency for the oil to adhere to the sand grains.

To meet this need two successful processes have been developed in this country, viz., forcing air or gas through sands, and forcing water through sands. These rejuvenation processes are now successfully applied in the older fields with consequent recovery of oil hitherto regarded as lost. Flooding methods, as used in the Bradford field of Pennsylvania, are probably limited in their application to the older Appalachian fields. Repressuring and the use of gas compression is meeting with success in the mid-western fields as well.

Conservation and Fuel Oil Supply.—The process of cracking gasoline from fuel oil has effected conservational economies of a considerable value, which significance is not yet fully grasped. Cracking has doubled our potential gasoline sources. The early cracking processes were limited to the cracking of the lighter distillate fractions leaving untouched the fuel crudes and those of high sulphur content, such as the California, Mexican, and Coastal crudes, the supply of which is very large. With modern cracking methods each grade of crude as well as fuel oil itself are potential sources of gasoline.

Fuel oil, then, becomes a vital factor in the entire program of oil conservation. Fuel oil may be regarded as the by-product resulting out of the rising demand for gasoline. With every increase in crude oil to meet the rising demand for motor fuel, a comparable quantity of fuel oil appeared on the market. At times, when the supply was not too large, this commodity found a reasonably profitable market in railroad fuel, bunkering, public utilities, fuel for refinery operations, and house heating. Overproduction conditions in the crude industry during the past few years, however, served to increase stocks of fuel oil to unwieldy proportions for, although the cracking processes made it possible to convert some fuel oil into gasoline, the incentive for complete cracking was absent since the gasoline market, too, was glutted. Nor was it possible to raise the price of fuel oil to a profitable level. In most of its outlets, fuel oil must compete with coal, and the cost of coal determines the price of an equivalent amount of fuel oil. The situation, therefore resolves itself down to this: Large production of crude oil tends to hasten exhaustion of oil reserves and at the same time flood the market with a commodity which must compete with low-priced coal. While this condition exists, the refineries are compelled to handle a large bulk of material out of which they derive very little profit or none at all. In fact, in extreme cases of oversupply, when the price of fuel oil dips below the coal equivalent level, it is frequently sold at a loss.

In the meantime, the refineries have in their possession, in the cracking and hydrogenation processes, the means of converting this fuel oil into gasoline and thereby taking it out of the realm of coal competition, if only the flood of crude could be stopped. Although this explains partly the attitude of the refiners in attempting to force curtailment of production, there is, moreover, an additional incentive for support of the conservation movement. The manufacturers of oil products have a tremendous investment in refineries, cracking plants, pipe lines, tank steamers, tank cars, and incidental equipment. This branch of the industry seeks permanence as well as profits, and both of these are more likely to be achieved if they confine their manufacturing activities to meet the gasoline market and reduce their fuel oil output to a point where it can be made to return a profit comparable with gasoline. Prolongation of the oil reserve gives a more assured outlook for the owners and investors of oil-refining properties.

Recovery of Natural Gasoline.—Rapid strides in the recovery of natural gasoline from gas has been an important contribution to the economy of petroleum utilization. At the end of 1929 the natural gasoline industry recorded a production of two billion gallons, enough to supply $3\frac{1}{2}$ million automobiles. This seems incredulous considering that only 16 years previous to this date, the industry was producing only 24 million gallons. The essential value of this industry is that it removes gasoline from the gaseous fuel in which its presence is of little effective value, and adds it to the stock of petroleum's most valuable product—automotive motor fuel.

A CONSTRUCTIVE ECONOMIC POLICY

The uneconomic management of the producing end of the oil industry, as exemplified by the existing methods of oil recovery and the losses resulting from overproduction, can end only in a premature exhausting of oil resources, for which industry will be unprepared. Excessive production, the result of several interlocking factors—geologic, economic, legal, and human—can be halted only by an extraordinary degree of cooperation within the industry itself. The first attempts to stabilize production such as at Seminole, Yates, Winkler, and Hendricks pools in the Mid-continent field, were only partial successes or temporary palliatives because they were isolated and unrelated attempts and not part of a planned and comprehensive policy.

The formulation of a policy of orderly development of oil must take into consideration the functions of oil products, and the geologic, legal, technical, and economic conditions under which the raw material is produced.

Oil may be regarded as indispensable for industry and transportation, for fuel, and for national defense. An appreciable decline in oil for even a two-year period would slow down the wheels of industry and bring serious industrial depression. The possibility of a future shortage of fuel and lubricating oils, not to mention gasoline, must be avoided or our manufacturing productivity will be curtailed to an extent not easily calculated. The aim of a conservation policy is clearly evident—*the maintenance of an uninterrupted flow of oil products to meet present and anticipated future needs.*

If the aim of a conservation policy is quite clear, the formulation of a comprehensive plan which will accomplish this aim is more difficult. Any plan which is conceived can be tentative only because of a lack of definite knowledge of the extent of oil reserves and the possibility that technological improvements in fuel use may make any specifically formulated policy of to-day useless on the morrow.

Ultimate exhaustion of the present type of oil deposits, particularly the cheap flush pools, must be expected. How long oil will last with present methods of production and forms of use can only be conjectural; but if we accept, for purposes of discussion, the figures arrived at by the Committee of Eleven of the American Petroleum Institute—26 billion barrels [9]—this quantity would be used in less than 30 years. That this reserve cannot be discovered and recovered in 30 years is evident so that some measures of conservation and substitution are necessary and cannot long be deferred.

The elements that must be considered in the formulation of an oil policy conceived upon the principle of most effective possible recovery and economical use are:

1. The physical characteristics of oil deposits.
2. Property characteristics of oil deposits.
3. Engineering aspects of oil production.
4. The organization of the oil industry.
5. Legal and constitutional rules under which the actors in the oil drama must play their part.
6. Industry's demand for oil products.

[9] American Petroleum: Supply and Demand, a Report to the American Petroleum Institute, 1925.

Physical Characteristics of Oil Deposits.—Oil is found in pools of all sizes from the small pools of the Appalachian fields to such enormous pools as Seminole, Smackover, Santa Fe Springs, Cushing, or Long Beach, with daily peak productions of 300,000 barrels or more; at varying depths from less than a hundred feet to a mile and a half in depth, under widely differing pressure intensities; the ease with which oil flows or is lifted out of the well; with or without gas. Inasmuch as these physical factors influence markedly the production methods to be employed in recovering the oil, the first requisite of efficient, economical, thorough, and most complete oil recovery is an engineering study of the physical conditions and an adaptation of production methods to fit the individual pools. Thus it has been shown that oil production by a large operator with competent engineering staffs and adequate facilities can produce oil more cheaply than small drillers.[10]

The application of sound engineering principles in the drilling of an oil pool may be, and in most cases is, thwarted by the property relationship of the oil. What logic and common sense would prescribe as a reasonable method of drilling a pool cannot be accomplished because several individuals, with non-cooperative minds, own separate portions of oil in a pool which ought not to be divided in the process of recovery. A comprehensive economic policy must work out a formula which will result in the interests of the property owners coinciding with the engineering aspects of handling a given pool.

A third factor that affects the course of oil production is the organization of the oil industry. The industry, as previously noted, is divided into four branches—*production, transportation, refining, and marketing.* These activities are accomplished through corporations, some of which are integrated to include some or all of the four branches, some of which engage in one activity only, such as production or refining. It is the latter group that is likely to be responsible for lack of coordination between producing and refining, or between refining and marketing, with resultant losses of capital, or oil, or of profits. The desire to expand the sales of gasoline, when abundant supplies of crude were

[10] "An economic study of the California petroleum producing industry made a few years ago by the Federal Trade Commission, indicated that the average large producer (with an output of one million barrels or more per year) is able to produce oil for 43 cents per barrel with a capital investment of $2.79 per barrel of annual production, while the oil produced by the average small operator (having an output of less than 50,000 barrels per year) under similar conditions, costs $1.21 per barrel and the capital investment per barrel of annual production is $10.52. It is apparent that there is a considerable advantage in the larger scale of operation."—Economic Losses in the Petroleum Industry, by L. C. Uren, before the Federal Oil Conservation Board, Feb. 10, 11, 1926, Hearings, p. 147.

cheaply available, led to an overproduction of refining capacity. This in turn brought about an excess of distributing facilities, accompanied by putting new dealers in the retail business and an orgy of pump loaning and similar practices, all in an effort to find new outlets for surplus gasoline. The result was a reduction of gallonage per pump and a mounting cost of distribution. Without in any degree increasing the total consumption, the industry thus tends to destroy its profits by its costly and uneconomic methods of dealing with an oversupply. The outcome of such practices manifested itself, in 1929, when the late summer peak demand for gasoline was accompanied by a weak gasoline market and a still weaker fuel oil market. Such untoward occurrences as an unwieldy supply of fuel oil stocks, or too much gasoline, indicate a lack of coordination of the branches of the oil industry from the pool to the filling station.

The market demand for oil products ought to be the governing factor in determining the supply of crude as well as of gasoline and fuel oil. A constructive economic policy must effect coordination. That trends in the oil industry are pointing toward an integration of the elements of the industry is indicated by the formation of mergers, the consolidation of producing properties, and a corporate integration of the several branches of the industry.

An integrated industry is not synonymous with monopoly in the industry for there can be several integrated oil companies competing among themselves.

The above, briefly, is a bird's-eye view of the engineering, economic, legal, and business aspects that must be marshaled into a harmonious, cooperating organization for the economical recovery of oil, and its delivery, without unnecessary wastes or costs, to the consumers. This has been accomplished to a certain degree in iron and steel, in copper, in aluminum, and needs attention in oil.

The integration of the oil industry offers opportunities for economies in several aspects. Considered from market aspects, the oil company can, with a reasonable degree of accuracy, delimit its economic marketing area, study the gasoline, fuel oil, and lubricating market possibilities and regulate the output of its refineries to meet this demand. Where a competing organization exists, the calculations of the market possibilities become more involved but the same principle holds. The activities of the crude-producing units of the organization could be completely subordinated to the requirements of the marketing and refining units. Where the organization has holdings of oil lands in foreign countries as well as at home, the domestic production program could more easily be coordinated with the imported oil.

Production by large units offers opportunities for effecting economies. "The small producer is an economic misfit in the oil industry. Lack of adequate capital often compels him to produce and sell oil in excess of the legitimate needs of the consuming industries, demoralizing markets and compelling others to match his ill-advised efforts, leading at times to large quantities of oil being sold below the cost of production. Such circumstances also breed wasteful conditions in the oil-consuming industries."

The organization of the entire American oil industry into completely integrated, but competing, units is probably unattainable and possibly undesirable. In spite of the trend in this direction, there are still in operation units engaged solely in production, transportation, or refining. Particularly, in the production branch, the divided ownership of many oil properties will prevent complete integration. These need not necessarily be a menace to the orderly development of the industry, or carry the constant threat of demoralizing the market. Adjustments can be made whereby these independent units fit into the industry in a constructive manner.

Various methods of stabilization, especially where the producing units are small, have been suggested or attempted. Prorations and shutdowns, while useful in extreme emergencies, are nowhere regarded as more than temporary expedients. They are difficult to enforce and do not eliminate waste, which is so necessary to reduce costs. Without exception the many studies that have been made by the Federal Government, by the American Petroleum Institute, and by many individuals within the industry, have resulted in the conclusion that general adoption of what has now come to be known as unit operation offers most promise as a first step in bringing about the objects sought.

Unit Operation.—The term as it is being used in the industry has not yet reached an exact definition but in general it implies that all properties in the respective oil and gas pool shall be consolidated into a single operating unit in some manner that will eliminate the competitive drilling-drainage feature in its development and operation, and will permit utilization to a maximum force of expulsion native in the reservoir.

The natural unit in oil deposits is the single pool, large or small, and unit operation is in essence nothing more or less than accepting nature's decree and seeking to work in harmony with it. Unit operation is purely an engineering matter and a local matter, because commonly an oil pool is a relatively small production unit in the country's oil business. Then, local cooperation in the orderly exploitation of an oil pool is not even a step toward a country-wide merger for the purpose of monopoly. There need be no fear that this observance of natural and economic law involves any violation of statutory law.

This type of development is widely used in oil fields outside of the United States where divided ownership of a pool is less prevalent. The effectiveness of unit operation is strikingly demonstrated in the exploitation of the famous Masjid-i-Suleiman (Temple of Solomon) field in Persia. The method of development and the results obtained are described by Oliver and Umpleby as follows: [11]

> It is 20 miles long by 4 miles wide, operated as a unit. It was opened in 1912. . . . Gas was found on top of the structure but the gas wells were closed in and the gas is permitted to escape only through the wells drilled into the oil zone. It thus drives oil ahead through the pores of the reservoir rock to the point where pressure is relieved by an oil well. The wells averaged 80,000 barrels per day initial and continue large until they show an excess amount of gas by virtue of the gas-oil level in the reservoir becoming lowered. Then they are closed in and the wells lower on the structure are opened.
>
> The potential daily output of the pool is greatly in excess of that which is utilized, *although only a small number of wells have been drilled on this large structure in* comparison with characteristic development in the United States. The pool has produced 300 million barrels of oil and has many years of proved reserves at the present rate of extraction. The oil wells have flowed, and continue to flow, their production at all times, as the owners express, "with no more trouble than opening a tap to draw water for the bath."

Very complete recovery from the reservoir rock is being made in this pool by the unit type of development. It will be noted that in this pool oil wells are permitted to flow until they change to gas wells, whereas under competitive development gas wells are permitted to flow until they become oil wells.

This method of production, making possible the utmost economies, illustrates the comparative disadvantages under which the United States petroleum industry with competitive extraction methods is competing in world markets with output of foreign oils.

The logic of the situation points inevitably toward unitization of pool operation in this country. The formulation of a workable plan is the immediate need. Most students of the industry are in agreement that the consumer, the individual operator, the individual royalty owner, and the general public, as well as the labor employed would, each and all, be greatly benefited if individual oil pools were operated as units; but general adoption of the practice in the United States has been delayed because information as to its advantages has been lacking and satisfactory means have not been developed to bring about consolidation.

[11] Oil and Gas Journal, February 27, 1930, p. 39.

On this account certain objections to it have arisen which may be grouped under the following heads:

1. Fear that violates the anti-trust laws.
2. Contention that it reduces personal control of property.
3. Fear that it would delay income from property.

When oil is obtained from more than 300,000 wells, and eight widely separated producing districts in the United States, and engaged in by thousands of operators, it is difficult to conceive of a violation of the law, if a handful of operators on one reservoir decide to pool their efforts to bring about the most effective and complete recovery. If an agreement existed among the owners of various pools, the procedure might be open to question, but when these pools are exploited independently of each other, the charge of collusion can not be made. The effect of unit operation is, merely, to make the pool the unit of competition rather than the individual well.

In fact, under unit operation, the trend would be away from monopolization. Competitive drainage makes vast aggregations of capital necessary in one organization in order to reach out constantly from point to point for a crude supply. If, however, methods of development become such that compact deposits of crude can be proved and made available to be drawn upon as needed over a period of years, small refining and marketing companies owning or holding interests in one or more such units will have little necessity, and therefore less tendency, to consolidate with others. Many complete small organizations will be developed rather than a few vast ones. Unit operation will, of course, be likewise advantageous to the large companies in that it will also give them dependable crude supplies; but it will remove much of the incentive for the large companies to consolidate with other large companies and become still larger. It is desirable to the large company as it is to the small company, but not nearly so necessary.

In regard to the second objection, the practical effect of competitive drilling is to reduce rather than enlarge control over a piece of property. The individual property owner, under existing conditions, is compelled to regulate his activities by the action of his neighbors, drilling to offset his neighbor's drilling, whether he wants to or not. Under unit operation he joins the plan for an orderly development of a pool on an equal basis with all other parties involved.

The third objection can be overcome by agreement among the operators at the time the cooperative compact is made. Some owners would prefer to delay extraction to satisfy later needs, or for better market conditions, whereas others would prefer immediate extraction.

Trading arrangements could be made among stockholders in a unit operation that would enable the desires of each to be taken care of in accordance with his daily or monthly needs, provided of course such trading arrangements came within the accepted proved reserve estimate.

Benefits of Unitization.—General adoption of the unit plan of operation would insure for the consumer a permanent and stabilized supply, at a lower average cost over a long period of years. For the producers, it means lower investment, development, and operation costs; more oil per acre; increased gas value; a more dependable supply of crude. These advantages also would accrue to the royalty owner.

The stake of the public in the inauguration of this plan means stabilized labor conditions, permanent communities, and enormous savings of natural resources in which the people as a whole have a vital interest.

What Steps Are Being Taken.—The first steps in the inauguration of a better policy in relation to oil grew out of the demoralizing conditions attending overproduction in the Seminole in 1926 and 1927. In response to appeals from leaders in the oil industry as well as noted public officials interested in the condition of the industry, President Coolidge, in September, 1924, addressed a letter to the Secretaries of War, Navy, Interior, and Commerce, constituting the Federal Oil Conservation Board.

The Board addressed questionnaires to representatives of more than 300 of the country's oil producing, refining, and distributing companies and various associations and institutions identified with the oil industry. The reports returned by the industry were considered by the Board in preparing its reports to the President and Congress. Public hearings were also held on February 10 and 11, 1926, and on May 27, 1926, in order to afford full opportunity to amend or submit additional data or views before completion of the report.

Suggestions of the Federal Oil Conservation Board.—A committee of nine appointed by the Federal Oil Conservation Board to consider a legislative program for the conservation of the gas and petroleum resources, after an exhaustive study, submitted their recommendations.

The method of cooperative development of and production of single pools or fields was considered the most effective remedy for the evils of waste and overproduction. Therefore this Committee recommended that both Congress and the legislatures of the oil-producing states be asked to pass legislation which will unequivocally remove cooperative agreements from the purview of laws forbidding restraints on commerce.

For periods of overproduction a further step was recommended so that, during such a period or in anticipation of one, agreements curtailing the development and production of oil shall not be in violation of the laws, state or federal, forbidding restraints on competition; that a period of overproduction permitting of such agreements be deemed to exist only when so declared by suitable governmental authority, and be deemed to end when that fact is similarly declared; that all such agreements be subject to supervision by suitable government authority, be filed with it as a condition of their legality, and do not become effective until they are so filed; and that the supervising authority has the right to abrogate any agreement filed which for any reason it judges not to be in the public interest.

As the granting of permission for such agreements would be a conservation measure, and as, also, it might be a matter of distinct importance, it would seem not unfitting that the governmental authority which might declare when such agreements could be made and the period for which they should be effective and have supervision over them, should be the Federal Oil Conservation Board itself.

The members of the committee also agreed that waste of gas should be prohibited by law but were unable to determine the form that this legislation should take. Hence they suggested immediate further study into the matter of the waste of natural gas in order that legislation might be formulated which would forbid such waste as fully as could be done without working injustice and unreasonable hardship. They also suggested changes in the law governing the mandatory leasing of Osage Indian lands.

A committee of the Minerals Section of the American Bar Association, whose report was submitted simultaneously with that of the Committee of Nine, doubted the efficacy of voluntary cooperative agreements for the exploitation of a pool or field.

From the evidence assembled your committee is of the opinion that voluntary action on the part of the industry will not in the near future, and perhaps never, meet the problem. The reason for this is not far to seek. The answer lies in the never-changing dictates of human nature. A refiner holding a single lease in an important and prolific oil pool, needing the crude for his business, will drill without restraint and produce to capacity regardless of the fact that his operations necessitate the same intensive drilling and producing campaign on the part of every other operator in the pool. Again, a producer owning one lease in a pool, driven by financial necessity or animated by the natural desire to "make hay while the sun shines," will act likewise, regardless of the consideration that his operations will be followed by a similar intensive and speedy work by his competitors in the pool. From the narrow point of view, these practices can not be condemned. On the other hand, with the problem of national conservation at stake and taking into account also the correlative rights and obligations of the operators in the same pool, your committee can not believe that this condition should be permitted to continue.[12]

To overcome the dangers of wasteful production of oil, unpreventable through voluntary cooperative agreements, the committee of the American Bar Association proposed a measure providing for the compulsory cooperative development and operation of pools, by invoking the police power of the state. In its concluding paragraph, this report of the American Bar Association says:

The inquiry of your committee has involved serious economic questions as well as debatable propositions of law. We are convinced that the American petroleum industry will never find its proper place in our economic structure until it solves the problems that arise from the competitive drilling and operation of oil and gas pools. Whether that is to be accomplished by voluntary action in the industry or by the compulsion of law is yet to be determined. After an extended inquiry into the two possibilities, we have reached the conclusion that, by force of circumstances entirely beyond the control of the industry, comprehensive voluntary action is improbable if not impossible. Upon the basis of this conviction your committee proposes one compulsory measure.[13]

In spite of the pessimistic views of the committee of the American Bar Association in its report on voluntary unitization, sentiment among oil producers is opposed to compulsory cooperative action. This method would probably be involved in so many legal difficulties that the leaders in the industry are determined to avoid it except as a last desperate expedient. Voluntary unitization, on the other hand, is entirely in harmony with American conception of property rights, but its successful and general adoption is dependent upon a more widespread understanding of the issues involved.

The movement should be promoted through education and persuasion rather than direct compulsion, but on the other hand those who persist in operating their properties on a competitive extraction basis might well be restrained from so operating them as to interfere with the proper and reasonable rights of other operators who are privileged to drill into the common reservoir.

Federal Action.—On March 12, 1929, a sweeping change of policy of the government regarding the exploitation of oil on public and Federal lands was announced by the Hoover administration. Sale or lease of government lands, whether public lands, naval reserves, or Indian lands, were withdrawn from development. The President, out

[12] Report III of the Federal Oil Conservation Board to the President of the United States, February 25, 1929, p. 17.

[13] Report III of the Federal Oil Conservation Board to the President of the United States, February 25, 1929, p. 4.

of his previous experience on the Federal Oil Conservation Board, no doubt was well informed on the effect of the government's policy of leasing upon the state of overproduction existing at the time, and the effect upon the depletion of the nation's reserve. Since 1920, about 10 per cent of the domestic oil output has come from lands in which the Federal Government controlled the mineral rights. Over half of the production (1928) came from Indian lands. Leasing on these lands is mandatory in the case of the Osage Indian lands and, at the discretion of the Secretary of the Interior, for other Indian lands. It is probable that leasing on these lands will not cease altogether but will be reduced considerably.

Oil production on the naval reserves, since 1926, has been carried on only for the purpose of preventing losses by drainage or waste of gas.

Aside from the naval reserves and Indian lands, the public domain has furnished about 25 per cent output on government lands. Prospecting permits for oil and gas, and leases for known oil and gas deposits in the public domain can be and have been granted by the Secretary of the Interior. In keeping with the announced policy of President Hoover, the Secretary of the Interior took action to curtail oil prospecting on the public domain. Five thousand pending applications for prospecting permits were rejected and registers of local land offices were instructed not to receive new applications. Steps were taken also to cancel all such permits where no drilling had been done or money spent in development. Where capital and effort had been invested the existing permits continued in force.

Almost at the same time that President Hoover put into effect his policy in regard to the production of oil on government lands, the American Petroleum Institute, cooperating with Sir Henri Deterding of the Royal Dutch-Shell group, approved and advocated a curtailment program covering the United States and South America, to begin April 1st. Production in 1929 and succeeding years was to be kept down to the 1928 level until stocks on hand were reduced and production balanced consumption. In fact, it was suggested that, with the steady perfection of refining processes, the 1928 levels might prove to be too high during the next four or five years, taking into consideration the larger gasoline yield due to improvements in refining methods. In this event, a further cut in production was planned. The reduced requirements will come about by increasing the gasoline output from 41.3 per cent, the average yield for 1928, to over 60 per cent by known and tested processes. Indeed, increased production was not to be permitted until the maximum recovery of gasoline and other essential oil products had been accomplished.

The committee of the American Petroleum Institute responsible for outlining the curtailment plan was fully cognizant of the difficulties of formulating a comprehensive policy suggesting immediate curtailment to the 1928 level as an initial step.

Further study of various phases of the oil industry in relation to Federal and state legislation, domestic restriction, the interest of non-producing countries, elimination of wastes, cooperation among oil-producing states, natural gas control, leasing laws, scientific methods of prospecting, and an estimate of oil reserves, was suggested by the committee to the American Petroleum Institute.[14]

The carefully laid plans of the American Petroleum Institute, although looked upon with favor by members of the Federal Oil Conservation Board, were upset by the Attorney-General of the United States, William D. Mitchell, in an opinion rendered to the Federal Oil Conservation Board. He says in part:

> The proceedings of the American Petroleum Institute indicate that the purpose of submitting the proposed agreement to the Federal Oil Conservation Board for approval is to obtain a sanction from the Federal government which may operate to make the parties to the agreement immune from the operation of the anti-trust laws. For the Federal Oil Conservation Board to grant approval under such circumstances would be assuming authority which it does not have.
>
> The board's only duties are to investigate and study for the purpose of recommending methods of conservation, and not with the intent that its action in approving or disapproving any plan would have any legal effect on the validity of the plan proposed. As the powers of the board are limited in this way, the question whether the proposed agreement would violate the anti-trust laws of the United States is apparently not a question arising in one of the executive departments on which the Attorney-General is authorized by law to give an opinion. Furthermore, it is not the practice of attorneys-general to give opinions as to whether proposed action by private persons would violate the laws of the United States.
>
> The proceedings of the Petroleum Institute make it clear that its members already realize that under existing laws such an agreement could not safely be made without the sanction of some officials of the United States authorized to give it and, as I have already pointed out, no such authority exists.[15]

The effect of this opinion was to cause an abandonment of the proposed curtailment program. In a further effort to effect a solution, Secretary of the Interior Wilbur, in a letter to R. C. Holmes, President of the American Petroleum Institute, suggested the formation of an Interstate Compact to accomplish stabilization. On June 11th, following, a conference of the oil industry, the governors of oil states, and the representatives of the United States was called at Colorado Springs

[14] See Oil and Gas Journal, April 4, 1929, for the suggested program of the American Petroleum Institute.

[15] Report of the Attorney-General, Oil and Gas Journal, April 11, 1929, p. 38.

to study further the question of oil stabilization, and especially to consider the proposal of Secretary Wilbur. The conference adjourned after a three-day discussion without taking action of a specific nature. The prevailing opinion of the conferees was that an interstate compact would be impractical or unconstitutional.[16]

In the meantime oil production in the ensuing months continued to rise and broke all records of output, reaching a high peak of 2,973,450 barrels, average daily production in the week ending August 31, 1929.

While all indications seemed to point to a complete breakdown of a curtailment program, two events occurred which served to stem the flood of oil and probably saved the oil industry from a serious crisis in the late months of 1929. The first of these events occurred in California, just as an orgy of overproduction was threatening, a drastic reduction in posted prices for crude oil was announced. The effect was that operators who had hitherto refused to cooperate in a program of curtailment and gas conservation fell in line, and a reduction of 300,000 barrels daily production was accomplished in three weeks. Oklahoma producers followed the example with the result that the close of 1929 witnessed a declining oil output.

The second event of major importance was the enactment of the California gas conservation law. Although this law was approved early in 1929, it was not until March, 1930, that it was declared constitutional and enforceable by court decision. This decision was the climax of a stubborn fight on the part of several Santa Fe operators who had consistently opposed enforcement. Under this law the blowing of gas into the air is prima facie evidence of waste. The law also contemplates a division of gas outlets and cooperative agreements for the conservation of gas. One paragraph in it is directed to excessive gas-oil ratios in fields where oil can still be produced with a low gas-oil ratio.

Another paragraph of the law permits a different type of action. By working along this line, the director of natural resources secured an order in the Ventura Field calling for the reduction of gas production there to the available outlets, plus a 10 per cent working surplus.

A successful application and working-out of the California gas law should furnish sufficient justification for the adoption in Oklahoma and Texas of a similar practice. Unquestionably, the easiest manner in which to comply with the gas law is by means of complete unit operation. While unit operation is still rather revolutionary for various reasons, the gas law promises a new form of regulation that will encour-

[16] Mockler, A. E., Compact is Believed Unconstitutional, Opinions of lawyers before the American Petroleum Institute Meeting, Oil and Gas Journal, May 23, 1929, p. 37.

age unit operation. This sort of procedure can be applied to the existing fields where gas is still an important factor.

The oil industry entered 1930 with a substantial decrease in crude production brought about in part by price cuts and the regulatory legislation in California. The rank and file of the industry as well as its leaders appear to have been awakened to the fact that unbridled production is unprofitable to themselves, nor will it be tolerated longer by the public. The time is opportune for a reconstruction of the industry along lines that means stabilization and profit.

CHAPTER XIV

NATURAL GAS

NATURE has endowed North America, and particularly the United States, with an abundant supply of natural gaseous fuel. Few of the other continents or nations can boast of an abundance of this valuable resource; indeed, in some of the leading nations of the world it is unknown. The ease of its recovery and the bountiful supply has led to an enormous, almost criminal, waste of large volumes of natural gas. Apparently the cheapness of the material caused the public to overlook the lavish waste of this unusually valuable resource. For natural gas has a considerably higher heating value than its manufactured competitors and at the same time, is obtained more cheaply. The relative value of natural gas and various types of manufactured gases is as follows:[1]

	B.t.u.
Natural gas	868 to 1027
Coke oven gas	583
Coal gas	573
Carburetted water-gas	505
Blue gas	300
Producer gas	150

The Federal Oil Conservation Board characterized the waste of natural gas as a triple waste—the waste of a gaseous fuel, the loss of gasoline contained in the natural gas, and loss occasioned by the dissipation of gas pressure in oil wells with which the gas is associated. Recognition of its value, however, is bringing about a change of attitude by the industry and the public. Efforts to save the gas and to extract the valuable natural-gasoline content are increasing even in oil fields remote from organized gas transportation lines. Conservation of gas pressure in oil pools is receiving more attention by oil men and legislation has lent its support to this movement.[2] The importance of gas

[1] Camp, J. M., The Making, Shaping, and Treating of Steel, Carnegie Handbook, 1924, p. 73.

[2] Stockman, L. P., California's Gas Conservation Law, Oil and Gas Journal, May 9, 1929, p. 47.

pressure conservation has been noted in a discussion of the oil industry. In relation to the services of gas in industry and domestic cooking, its conservation and the prolongation of the reserve is equally important. For gas is a commodity of unique characteristics. It cannot be stored above ground to any appreciable extent, nor can it be transported except within the state and to adjacent states. Hence the geographic facts of distribution and state output play a more important part than in the economics of its associate, petroleum.

The general fact of a steady increase in total production does not contradict the fact that a decline may and does occur in a local natural gas area. In view of the limitations surrounding its distribution over great distances, the community which has built up industries based on the use of natural gas cannot be benefited by an increase in output elsewhere. Hence the conservation and protection from damage of local gas reserves is of the utmost importance. Exhaustion of supply can be replaced by the substitution of manufactured gas, but this is usually accompanied by an increase in cost and a lowering of heat value per cubic foot, both of which factors may seriously affect industries built upon the use of natural gas.

Gas is produced in twenty states, although six of these, Oklahoma, California, West Virginia, Texas, Louisiana, and Pennsylvania, account for about 80 per cent of the output. Three natural gas areas of importance may be noted, the Appalachian Field, the Mid-continent and California.

The *Appalachian gas field* is considered to include all of the gas-producing districts east of central Ohio and northeast of central Alabama. This was the first important natural-gas district to be developed. Although this territory covers a large area, it is not the most important in production. Many of the gas fields have passed the peak of production and now yield relatively small quantities of gas; this condition is especially typical of Pennsylvania, New York, and West Virginia. In spite of considerable activity in bringing in new wells and drilling to deeper sands, it is apparent that gas production is declining in the Appalachian Field.

In the *Mid-continent Field* production of natural gas showed a very rapid increase since the World War and the future supply of gas is not a matter for as much immediate concern as in the Appalachian territory. Although much of the gas produced in Louisiana, Texas, and Oklahoma fields is used for industrial purposes within the producing states, there is considerable interstate transportation of gas.

The gas fields of California are located chiefly in the southern portion of the state in association with the oil fields. Rapid exploitation of the California oil resources has brought about a terrific waste of natural gas, mounting to untold millions of cubic feet of gas. Efforts to conserve this fuel were inaugurated late in 1929 when the California gas conservation law, also designed to curb overproduction of oil, went into effect.

Distribution of Natural Gas.—Natural gas is distributed to consumers through pipe lines. Some of the large industrial consumers are close to the source of supply, for example, the carbon-black producers of Louisiana and certain refining companies and smelters in various locations throughout the country. More than one-third of the natural gas is thus disposed where pipe-line costs and transmission problems are not of great importance.

Recent developments in long-distance transportation of natural gas constitutes one of the most noteworthy achievements in modern economic history. Major industrial areas, hitherto dependent upon solid or liquid fuels, have been brought within the range of natural gas service through the construction of pipe lines covering distances which, until recently, were considered beyond the limits of immediate possibility.

Recognition of the merits of natural gas as an ashless fuel of high heat value, definite conclusions as to the adequacy of its supply, and surveys of potential demand in areas under consideration, were combined with the engineering ability and financial support necessary for these new accomplishments in transportation. Much of this construction has been so recently completed that its full effect is not yet apparent.

During 1928, more than 1 trillion 568 billion cubic feet of natural gas were produced and delivered to customers. Of this 36.6 per cent was consumed as fuel in oil-field operations and 7.3 per cent for fuel needs at petroleum refineries, making a total of nearly 44 per cent consumed within the oil industry. Manufacturing and industrial plants utilized 19.5 per cent of the total, 4.9 per cent was consumed in the generation of electric power at public-utility plants, and 11.2 per cent was used in the manufacture of carbon-black. A total of 79.5 per cent was used in industry and 20.5 per cent for domestic purposes. The quantity of natural gas produced and delivered to consumers during 1929 reached a total of approximately 1 trillion 918 billion cubic feet, an increase of about 22 per cent over 1928.

Prior to 1927, transportation of natural gas over a distance of 250 miles was regarded as an outstanding engineering accomplishment. Since then, several long distance lines have been completed, or are projected, noteworthy among them being in the Mid-continent and

Gulf fields, where Memphis, New Orleans, St. Louis, Denver, and adjacent communities are supplied with natural gas. A 420-mile pipe line has been built across Mississippi, Alabama, and Georgia to deliver natural gas from Louisiana to Birmingham, Ala., Atlanta, Ga., and other communities in these states. Salt Lake City and Ogden, Utah, are served with natural gas from the gas fields of Colorado, Wyoming, and Utah. A 950-mile pipe line extends from the Amarillo field, in Texas, to Chicago; the pipe line to San Francisco has been extended northwards to Oregon and Washington.

Reviewing this list of natural-gas lines and anticipating the building of still longer lines, the question naturally arises as to what new conditions have made possible the building of natural-gas distributing systems extending farther and farther from the gas fields. The subject is one in which both engineering and economic factors are involved. Every natural-gas distribution project requires the detailed consideration of three major factors, namely:

1. Assured supply of gas for long-time periods.
2. Assured markets.
3. Costs of construction and operation.

Insofar as the decision to undertake a natural gas distribution project is concerned, the first two items have relatively more weight than the third. In other words, cheaper pipe-line construction, made possible by the use of improved methods and the application of advanced engineering science, is only one of several items in establishing the first cost of the project; it is essential to have an assured gas reserve, capable of supplying a market over a long-time period, in order to attract the necessary capital to finance the project.

Many long natural-gas transmission lines probably would have been built to connect newly discovered fields with marketing centers even with higher construction costs, for the size and nature of the markets and the extended life of proved reserves would assure the amortization of investment in a connecting pipe line long before the natural reservoirs were depleted. Improved methods of pipe-line construction have decreased the cost of the long gas lines built during the past several years. The use of large-diameter pipe made of high-carbon steel with greater ultimate strength and the handling of gas at high pressures, are developments of outstanding importance in long-distance transmission.

With the advent of conditions requiring a pipe line to deliver maximum peak-load of or exceeding 250 million cubic feet per day, the important problem of design of a natural-gas pipe-line project included the study of:

1. Size and weight of line and working pressures.
2. The number and size of compressor stations, together with the desirable compression ratios.
3. Relationship between investment and operating costs with the view of obtaining a properly balanced and economical system.

The principal item of cost in a pipe-line project is the cost of the pipe itself. This cost varies directly as the weight, which in turn varies directly as the diameter multiplied by the thickness. With increasing diameter, the thickness of the pipe must be increased proportionately to withstand the same pressure. Because an increase in the diameter of pipe increases the capacity more rapidly than the corresponding increase in cost, the general tendency has been to use pipe of sufficiently large diameter to deliver the capacity required at pressures up to 350 or 400 pounds per square inch. However, the possible economy which may be effected in gas transportation through lines of smaller diameters and greater wall thickness under pressures as high as 1500 pounds per square inch is being considered. It has been suggested that while the costs per lineal foot of line may be more for this type of construction, the cost per cubic foot of natural gas delivered may be less.

Several gas companies have reduced the cost of their pipe-line construction materially by using so-called telescope lines. These lines are made up of sections of pipe of different diameters, the diameter increasing in the direction of flow, as the pressure decreases. For example, where a 16-inch line is required, its equivalent may be built with 14-, 16-, and 18-inch pipe; or a line of uniform diameter may be built with the weight of pipe decreasing in the direction of flow so that pipe with thinner walls is used where the pressures are lower. Telescopic design of pipe lines has the effect of reducing the total weight of the pipe and consequently the cost. Telescopic lines should be especially economical where high initial pressure exists and where there are long distances between compressor stations. The efficiency of flow through telescopic lines is being studied by Federal and industrial agencies to determine the advantage in amount of gas handled in these lines as compared with lines of constant diameter.

Further economies have been effected by the use of better welding methods, longer lengths of pipe, protective coatings, and the substitution of power machinery for hand labor in pipe-line construction.

Need of Full Utilization of Gas.—The expansion of facilities for distributing natural gas has demonstrated the public demand for this best of fuels. By virtue of its convenience as a domestic fuel and its economy as an industrial fuel, natural gas is winning recognition in communities and districts where it has been unobtainable until technical skill combined with courage on the part of the public utilities made its wide distribution a reality. With this increased and growing market for natural gas, not only the gas produced from the so-called dry-gas reservoirs is in demand, but there is a growing realization of the commercial value of the gas delivered to the surface in conjunction with the production of oil. There is also a widespread realization of the importance of natural gas in its function as a propulsive agent in the production of oil. So it is that natural gas is now coming into its own as an item of large significance in the balance sheet of the oil operator.

The oil industry now also sees substantial profits in this fuel of high heating value which was previously disregarded. Attention has been repeatedly called to the enormous waste involved in the escape of gas into the air, but since aboveground storage of natural gas is plainly impracticable from the standpoint of cost, many executives, who thought in terms of oil, regarded escaping gas as unavoidable waste. Now that this natural resource, produced with the oil has taken on a commodity value as well, as a result of long-distance pipe lines, opinions and policies have changed. Moreover, production engineers are now pointing out the even greater importance of gas as the most efficient agent in extracting oil from the ground, with the result that it is realized that the prevention of the escape of gas is highly desirable in the practical business of producing oil.

CHAPTER XV

IRON

IRON is the master metal of a metallic age. It forms the basis of the vast manufacturing activities concentrated on the lands bordering the North Atlantic Ocean and, in the present day, is the cornerstone of industrial and political power. For the nation that possesses a large iron-making industry also dominates in the manufacture of the non-metallic commodities. Such nations can support large populations with a high standard of living. Their industries bring within the reach of all their people a wide range of material conveniences and luxuries. Iron is man's most important metal in aiding him in his conquest over nature. The dominant position of iron in this significant relation to human welfare and comfort is due to characteristics of varying order of magnitude. First in economic importance, is the cheapness of the metal. Although one other metal, aluminum, exceeds iron in abundance, it cannot be wrested from its native state as easily and as cheaply as iron. A pound of aluminum is nearly 20 times as costly as a pound of iron. Iron, in its various alloyed forms, is a versatile metal. It can be made brittle or tough, hard or soft, pliable or elastic to suit the needs of the user. A delicate watch spring is as much a product of iron as the cast-iron cylinder head of an automobile engine, yet in each case the metal exhibits widely different properties and characteristics. The steel cutting tool of a lathe differs from a chilled iron plowshare not in metal composing it but in the manner in which the iron in each is prepared. No other metal is capable of giving the wide range in physical properties that make iron available for an almost unlimited number of purposes.

Iron possesses the property of magnetism. The significance of this grows in importance when one realizes that there are but few metals having this peculiar property to any degree and, of the metals that are cheap and abundant, iron alone possesses it. Hence our entire range of magnetic and electric appliances are dependent upon this one metal. It is essential for the construction of the dynamo, the electric motor, the telegraph and telephone, the radio, the compass, and the large number of electrical measuring instruments. The electrification of industry, the widespread application of electric power in manufacturing, transportation, communication abroad and in the home—all are built upon the magnetic property of iron.

Modern civilization is intimately dependent upon steel, and this dependence arises from the fact that ours is a civilization of machines.

The Rise of Iron and Steel.—Man has used iron for many centuries, at least as far back as 4000 B.C., according to the students of history.[1] Probably its use may antedate even this distant age, for iron corrodes very easily and all traces of early iron implements may have disappeared. The use of iron in large quantities, however, is comparatively recent. The American colonists used only a few pounds per person each year, and that for only a small variety of implements and fixtures. The art of iron reduction was too primitive to yield large quantities of the metal cheaply. Also the sources of iron ore were meagre, usually consisting of small beds of bog iron ore in carbonate form. Growth in the output of iron in the early period of American independence was slow. In 1810 consumption of pig iron per capita was 15 pounds; by 1850 it rose to 48 pounds and in 1870 it was 85 pounds. In the following decades consumption mounted rapidly so that by 1900 the amount of iron per person was 350 pounds. Several interlocking events conspired to bring about the rapidly growing importance of iron. The rapid expansion of the United States in agriculture and industry and in railroad building created a demand for iron and steel (later) in large quantities. Invention and discovery proved equal to the demand. In 1857 the Bessemer process of steel manufacture was invented and cheap steel in large quantities became a reality. Production of steel rapidly replaced cast iron. The industry in the latter decades of the last century was dominated by the Bessemer process. This proved to be the cheapest method of production. However, the ever-increasing demand for steel, which even the phenomenal success of Bessemer was not able to meet entirely, opened the field for other methods of steel production. The growing difficulty of the Bessemer process was a shortage of suitable types of ore. This method of steel manufacture requires ores containing less than 0.1 per cent of phosphorus for the acid process or an excess of 2 per cent of phosphorus for the basic Bessemer. Neither of these types of ores are abundant domestically. Fortunately, the invention of the open-hearth process of steel manufacture came to the aid of the steel users. For a long time subordinate to Bessemer steel, the open hearth began to make rapid strides in the decade 1890–1900. In 1909 it surpassed Bessemer in output, and by 1929 it accounted for 85 per cent of the total steel output. As compared with Bessemer, its opera-

[1] Swank, J. M., Iron in All Ages.

tions are under better control and the product is more uniform and reliable. The yield of ingots compared with the total of metal charged is also higher than Bessemer.

The rise of open hearth was accompanied by discoveries of vast beds of easily mined, high-grade ore in the Lake Superior district. In 1884 the Gogebic range sent its first tonnages to the blast furnaces. Iron ore from the Vermillion and Mesabi ranges followed quickly until at the present time 85 per cent of the domestic ores, mostly non-Bessemer, are obtained from the six ranges of Michigan and Minnesota.[2]

Steps in the Manufacture of Iron and Steel.—From the iron mine to the finished steel product, iron goes through an intricate chemical and mechanical process. A vast array of equipment and a large variety of raw materials are brought into use to convert the raw ore into the many iron and steel commodities of commerce. The general steps of steel manufacture consist of (1) pig iron production, (2) steel ingot making by the Bessemer and open-hearth processes and to a smaller extent by the crucible and electric furnace methods, and (3) the shaping of ingot steel into blooms, billets, slabs, and rods—the principal forms of semi-finished steel. These in turn are converted into rails, beams, wire, sheets, castings and forgings, and a multitude of other products. Only the primary process will be reviewed.

Pig Iron.—Pig iron is the product of the blast furnace and may be regarded as the raw material for making cast iron, wrought iron, and the various kinds of steel. It consists of about 90 to 95 per cent iron and the remainder of such impurities as silicon, sulphur, phosphorus, and carbon—ingredients which are not removed in the process of smelting. The function of the blast furnace is to reduce the ores of iron to the metallic pig iron state. For this process, coke, limestone, and heated air are required. The production of one ton of pig iron requires about two tons of ore, $\frac{1}{2}$ ton of limestone, one ton of coke, and $4\frac{1}{2}$ tons of air. Combustion in the blast furnace is supported by means of an air blast heated to 1200 to 1400° F. The molten iron is drawn from the furnace at intervals from 4 to 6 hours.

Some of the pig iron is made into wrought iron. This is a very valuable product and much more of it would be used were it not for the high cost of production. The properties of this metal are so desirable that for some purposes its use is almost imperative. Its softness makes it easily worked into all manner of shapes, either hot or cold. It is tough, so that a wide variety of special articles such as nails, chains, horseshoes, etc., are made from it. The fact that it does not rust as

[2] Camp, J. M., and Francis, C. B., The Making, Shaping, and Treating of Steel, Carnegie Steel Company, 4th Ed., 1925.

easily as other iron or steel makes it popular as a material for making water and steam piping. It is easily magnetized and de-magnetized, which makes its use in electric-generating machinery mandatory. It is, however, too soft for rails, structural shapes, or heavy machinery.[3]

Steel.—In trade practice iron with a carbon content of less than 2.2 per cent, generally of less than 1.5 per cent, but having more than a mere trace of that element, is classified as steel. Steel is further classified, for commercial purposes, into three grades according to hardness: mild, or soft steel, containing less than 0.15 per cent of carbon; medium steel, containing from 0.15 to 0.30 per cent of carbon; and hard steel, containing more than 0.30 per cent carbon. Steel is characterized by relative toughness and, when tempered, by hardness and elasticity. It differs from cast iron in that it has a smaller percentage of carbon and from wrought iron by its freedom from slag.

At the present time there are four recognized processes in manufacturing steel; the Bessemer, the open-hearth, the crucible, and the electric-furnace. The Bessemer process consists in blowing air through molten pig iron contained in a suitable vessel, known as the converter, whereby its impurities are oxidized and removed. Molten iron is poured into the converter, subjected to a "blow" for 15 or 20 minutes, after which a measured quantity of carbon and manganese is added to complete the steel-making process.

The advent of the Bessemer converter is one of the great milestones in the progress of the steel industry, second only to the later open-hearth development. But for the birth of this rapid method of steel making by blowing air through molten iron, the development of the United States would have been greatly retarded. The idea originated, almost concurrently, with two men: William Kelly, an American, and the illustrious inventor, Henry Bessemer, in England. Although Kelly worked out the idea as early as 1847, he did not apply for a patent until 1857, two years after Bessemer's English patent was granted. After considerable difficulties Bessemer successfully established his process in 1860 at Sheffield.

The Bessemer process introduced a steel which could be produced in large quantities at a low cost and the effect of this process was far-reaching. However, it had certain limitations which compelled it to yield first place to another method known as the open hearth. The principal drawbacks of the Bessemer process are: First, a considerable loss of metal due to "spitting" of the converter during certain periods of the "blow"; second, the lack of absolute control of the carbon con-

[3] Aston, J., The Trend of Development in the Wrought Iron Industry, Trans. A.I.M.E., Reprint No. 1595–C.

tent due to the short time required for the process; and third, the fact that the process is not adapted to the use of the kind of ores most prevalent in the United States.

The open hearth was developed in England by William Siemens soon after Bessemer had given his invention to the world. The hearth, in this method of steel production, is shaped like a hollow pan, and will hold a pool of metal perhaps 15 feet wide, 30 feet long, and 18 to 24 inches deep. Heat is obtained from the combustion of gaseous fuel which spreads a torch-like flame over the molten metal. The advantages of this process over the Bessemer lie in the fact that a wider range of ores are available, there is better control of the operation, and a more uniform quality of steel is obtained.

The crucible process consists in melting pieces of wrought iron in a closed crucible of 100 pounds capacity, with or without the addition of carbon or other material. It is essentially a melting operation, but the metal is held in a quiet molten condition or dead melt for an hour or so to eliminate gases and oxides. A high quality of steel is made by this process. In this country crucible steel is being replaced to some extent by electric steel.

In 1880 there appeared a forecast of still another method of producing steel which was to take its place besides the crucible, Bessemer, and open hearth. In that year Siemens described to an English technical society a furnace in which he made steel by means of heat generated from electricity. The first experimental furnace was merely an indication of what was to come for it was not until sixteen years later that a commercial furnace for the steel industry was brought out in Italy.

Production of steel from electric furnaces was 666,000 tons in 1927, and although the quantity produced fluctuates from year to year, the production trend is upward. The field of the electric furnace seems to be in foundry and steel units of $\frac{1}{4}$ to 3 tons capacity for small castings and some preparation of steel for subsequent melting in crucibles.

Raw Materials of the Iron and Steel Industry.—An enumeration of all the raw materials that enter into the process of steel making would necessitate cataloguing a long list of mineral and non-mineral substances. So complex is our metallurgical industry that practically all known raw material substances cooperate in the making of the final product. A survey of these materials will not be attempted for it would lead us too far afield. A limitation of the discussion to a survey of the raw materials that enter the final product, those that aid directly in the process, and those that are of peculiar importance in the steel-making equipment will suffice. With this grouping the more important materials may be listed somewhat as follows:

1. Raw materials entering into the product itself:
   (*a*) Iron ore.
   (*b*) The alloy metals.
2. Raw materials aiding in the process:
   (*a*) The fuels—gas, coal and coke.
   (*b*) Fluxing materials—limestone, dolomite, silica, fluorspar.
   (*c*) Deoxidizers and recarburizers—ferro-silicon, ferro-manganese, spiegel, pig iron.
3. Materials peculiar to the plant equipment—refractories such as silica brick, clay brick, magnesia, lime, dolomite, bauxite, graphite, chromite.

Iron Ores.—Iron ranks fourth among the materials of which the earth's crust is composed and is second in abundance among the metals. The elements that exceed it in quantity are oxygen, silicon, and aluminum. The compounds of iron are widely disseminated in nature, scarcely a rock or soil exists which does not contain some of the iron-forming minerals. Its most prevalent form is in combination with oxygen or sulphur, while minor quantities of the metal are found in combination with silicates or carbonates. Iron is rarely found in the free state. The iron compounds which may be regarded as ores of commercial value belong principally to the oxide and the carbonate groups. The principal commercial ores of these two groups are hematite, brown ore, magnetite, and iron carbonate. Hematite, in its pure form, is an oxide or iron, containing 70 per cent metallic iron and 30 per cent oxygen. The brown ores differ from hematite in that they contain more or less chemically combined water. The water content reaches as high as 25 per cent in some forms of brown ore, while the iron content drops as low as 50 per cent.[4] Pure magnetite is the richest of the iron ores, having a metallic content of 72.4 per cent. It is well known because of its magnetic property. Iron carbonate, also called siderite, contains a little less than 50 per cent of metal. It is not an important source of iron ore in this country, but is used considerably in one of the leading English iron-mining districts.[5]

Characteristics of Commercial Ores.—To the lay mind, an iron ore is an iron ore and little thought is given to the factors which distinguish an ore body of commercial value from a non-commercial ore. These factors are both of a physical and an economic nature. With the pres-

[4] Eckel, E. C., Iron Ores, 1914, p. 19.

[5] Davis, H. W., Iron Ore, Pig Iron and Steel in 1926.

ent large-scale operation in the steel industry the first requisite of an ore body is to be of sufficient size to supply the blast furnaces for a long period of years. Mining machinery and transportation facilities will not be installed unless there is sufficient ore in sight to last throughout the life of the equipment. Another important consideration is the quality of the ore itself. Not only is an ore of high metallic content desired, but also one of fairly uniform grade throughout, of a physical structure suitable for use in the blast furnace and free from undesirable impurities, such as sulphur, excess phosphorus, or titanium. In some instances, ores of a grade below the standard specifications can be used by careful proportioning and mixing with higher-grade ores. Finally, the conditions of mining and the geographical location of the ore body must be such as to permit of profitable disposal of the ore in a competitive market.

World Distribution of Commercial Iron Ores.—The greatest iron-ore fields of the world are (1) the Lake Superior district; (2) the Lorraine ore field of northeastern France, Luxemburg, and southern Belgium; (3) the magnetite deposits of northern Sweden; (4) the ore fields of Oriente, Cuba; (5) the ores of Belle Isle, Newfoundland; (6) the ore region of southern Brazil; and (7) the ores of the Birmingham district. In each of these fields the potential yield of iron is estimated to be from one to six billion tons. Other deposits, the commercial importance of which is greater than that of the amount of reserves available, are located in Spain and northern Africa. The Lorraine field is advantageously situated with coal and limestone and is near some of the most important markets of the world. The iron content of Lorraine ore, however, is only about 30 per cent to 35 per cent while the Lake Superior ore averages over 50 per cent. Iron ores of Brazil and Sweden are high in iron, averaging from 55 per cent to 65 per cent, but these countries have a very limited supply of coal. The Brazilian field contains the most extensive known deposit of "low phosphorus" ore, used largely in the manufacture of ordnance material.[6]

[6] Consult also: Daniels, J., Iron Ores on the West Coast of Chile, Mining and Metallurgy, May, 1926; Eckel, E. C., Iron Ores of Northwestern France, Eng. Min. Jour., Vol. 127, No. 10, March 9, 1929, pp. 392–393; Kuhn, O. R., Iron Deposits of Cuba, Eng. Min. Jour., Vol. 121, No. 15, April 10, 1926, p. 607; Kuhn, O. R., Spain—the World's Oldest Producer of Iron Ore, Eng. Min. Jour., Vol. 121, No. 9, February 27, 1926, pp. 367–372; Kuhn, O. R., Scandinavia's Iron Ore Resources, Eng. Min. Jour., April 20, 27, 1927; Teixeira, Emilio, The Iron Ore Resources of Brazil and their Economic Importance, Eng. Min. Jour., Vol. 124, No. 19, Nov. 5, 1927, pp. 73, 734.

THE IRON ORES OF THE UNITED STATES

The Lake Superior District.—The iron and steel industry of the United States is built upon the vast ore bodies of the Lake Superior district. From a modest beginning of scarcely a million tons annually in the two decades following the Civil War the output of this district has increased to fifty million tons or more annually and provides approximately four-fifths of the entire output of iron ore in the United States. Although the iron ranges of this district are scattered over the states of Michigan, Wisconsin, and Minnesota, and the province of Ontario, the productive area consists of six narrow belts of iron deposits running in a northeasterly direction. In the order in which they were opened the six chief ranges are Marquette, Menominee, Gogebic, Vermillion, Mesabi, and Cuyuna.

The Marquette Range.—The Marquette range, in Marquette County, Mich., extends westerly from the city of Negawnee for a distance of about 30 miles. The main basin in this district is only about 3 to 6 miles wide, but outlying areas, which are commonly regarded as belonging to the same mining unit, make the north and south dimension about 20 miles. The maximum depth to which the ore bodies extend has not been determined, but they have been found to a depth of 2500 feet or more. The existence of the ore was first discovered in 1844 and the first ore shipments of importance followed the opening of the Soo Canal along the St. Mary's River in 1855. The ore is partly hematite of the red, soft variety, together with smaller quantities of magnetite and brown ores.

The Menominee Iron District.—The Menominee range is largely in the state of Michigan, but also includes more than 200 square miles in Wisconsin. It lies several miles due south of the Marquette range and, hence, is nearer to Lake Michigan than Lake Superior. The several mining districts of this range are grouped in an area about 50 miles long and 35 miles wide. The ore bodies of this range extend to a depth of 1500 feet or more. They range from a few feet to several hundred feet in thickness and vary from a few hundred to 3000 feet in length. The ores are on the average somewhat lower in iron content than those of the other ranges. Although these ores were discovered as early as 1867, no development work was done until 1872. The opening of railroad branch lines in 1880 and 1886 increased the output considerably.

The Gogebic Range occupies a narrow belt about 80 miles long, extending in a westerly direction from eastern Gogebic County, Michigan, across the Wisconsin state line into Iron, Ashland, and Bayfield counties, Wisconsin. The most productive part of the range lies in the state of Michigan. The ore bodies of this range vary greatly in size and shape, being several hundred feet in width and depth, and from several hundred to several thousand feet in length. Developments extend to considerable depths and ore is known to exist at least 3000 feet below the surface. The first ore shipment was made in 1884.

THE MINNESOTA RANGES

The Vermillion Range is located in the northeastern part of Minnesota, in St. Louis, Lake, and Cook counties. From the west end of Vermillion Lake it extends in a northeasterly direction to Gunflint Lake on the Canadian border. It is about 100 miles long and varies in width from 5 to 15 miles. Although mention is made of ore in this district as early as 1850, explorations were not made until 1875 when the deposits on Sondan Hill were discovered. The first shipment of ore was made in 1884, when railroad connections were completed, although the actual mining had been started some years before. The ore of this range is found to a depth of 2000 feet. The ores themselves are hard blue and red hematites, for the most part high in iron and low in moisture. A comparison of the output of the Vermillion and Gogebic ranges discloses an interesting contrast between centralized control, backed by adequate capital, in the Vermillion district, and competitive exploitation based on small undertakings and insufficient funds in the Gogebic district. Production in the latter moves upward by leaps, starts one season rising in excess and the next sinks back to deficiency; the output of the Vermillion, on the other hand, climbs with a regularity which is surprising when one considers the variable conditions of the market in which it has to be sold.

The Mesabi Range is one to excite the interest of every one engaged in the manufacture of iron and steel, because from it comes the greater part of the ore used for the production of pig iron today. It was opened in 1892, and up to 1927 748,000,000 tons of ore had been taken from its mines. It lies in Minnesota, northwest of Lake Superior, and extends in an east and west direction approximately 100 miles. The mines are shallow in comparison with other Lake Superior ore bodies, the average depth being 250 feet. The ores are mostly soft hematite and limonite. In addition to the high-grade ores now exploited, there are immense deposits of low-grade ore which will become more and more important as the higher grades approach exhaustion.

The Cayuna Range, which is the last range of any importance to be discovered, was opened in 1911. It extends in a westerly direction from a point about 60 miles west of Duluth and 50 miles south of the Mesabi range. It has two main subdivisions, the north and south ranges. The latter is more extensive, but the former, which occupies a belt about 10 miles long and 5 miles wide, contains the most productive mines. The glacial drift which covers this range is from 80 to 250 feet thick and there are no outcroppings of ore, which accounts for its delayed discovery. The first shipment of ore was made in 1911. Since that time production has increased steadily and from present indications it bids fair to become an increasingly important source. The ores are mostly of the non-Bessemer type.

Summary of the Lake Superior Reserves.[7]—Estimates of ore reserves for Minnesota, furnished by the Minnesota Tax Commission, and for Michigan, furnished by the Michigan Board of Tax State Commissioners, cover developed and prospective ore in the ground and ore in stock piles. The estimates for 1926 are as follows:

TABLE IX

ORE RESERVES OF THE SUPERIOR DISTRICT

(1926 Estimate)

Range	Tonnage
Mesabi	1,233,979,351
Vermillion	12,382,725
Cuyuna	55,090,529
Gogebic	53,342,720
Marquette	63,612,812
Menominee (including Iron River and Crystal Falls District)	66,639,492
Total	1,481,047,629

The Iron Mining Industry.—Since the Lake Superior ores occur in pockets or distinct bodies and vary much as to character and location, the actual mining of the ores is preceded by work of an exploratory nature. The presence of an ore body is first determined by geological examination, dip needle work, or shallow test-pitting. When the ores are non-magnetic, as in the Mesabi range, the dip needle is valueless.

After the presence of an ore body has been determined, further exploration is done by drilling two or three holes, usually with the diamond drill. In flat-lying deposits, such as the Mesabi, the limits of an

[7] Hotchkiss, W. O., Lake Superior Iron Ore Reserves, Mining and Metallurgy, Vol. 7, August, 1926, pp. 339——; Lake, M. C., Future of Lake Ore Outlined, Iron Trade Review, December 25, 1924; Van Hise, C. R., Leith, C. K., and Mead, W. J., Reserves in the Lake Superior District, U. S. Geological Survey Monograph 52, 1911, pp. 488–495.

ore body may be determined by drill explorations alone. Where the geologic relations of the ore body are more complex, as on the older ranges, it may be necessary to resort to the sinking of a shaft for underground exploration.

Methods of Mining.—Both open-pit and underground methods of mining are employed in the mines of the Lake Superior district. On the Mesabi range, the greater portion of the ore is obtained from the shallow, flat-lying ore bodies by open-pit mining, although, occasional deposits with limited operating area or excessive depth of over-burden must be mined by underground methods. On the older ranges, where the ore bodies often extend to great depths and usually lie at angles so steeply inclined to the horizontal that the surface exposures are small, underground mining methods are employed almost without exception. The depth of mine shafts varies from 250 to 300 feet on the Mesabi range to as high as 2000 feet on the older ranges. Open-pit mining has its greatest advantages over underground methods when the surface exposure is large and the over-burden is light. Mine machinery can be employed to much greater advantage and the tonnage output per man is many times that of the average underground mine. The possibilities of large scale production are evidenced when one considers that, in 1926, the Hull Rust Mine alone shipped 7,665,611 tons of ore—more than 10 per cent of the total domestic production. There is also a lower labor cost in view of the fact that, in open-pit mining, unskilled labor comprises the bulk of labor costs, whereas, in underground work, the miner is a rather high-class workman and he receives a relatively higher wage.

Grading the Ores.—The requirements of the furnace for an ore of uniform physical characteristics and chemical composition have brought about a system of analysis of the ore as fast as it comes from the mines. This is the work of the grader, who, from the analysis of the mine cars as submitted to him, makes a theoretical shipment in which the contents of silica, phosphorus, and possibly manganese, the determining factors in the valuation of an ore for a particular purpose, must fall within certain predetermined limits.

TRANSPORTATION OF LAKE ORES

The Rôle of the Railroads.—Without adequate railroad facilities for the transportation of the ore from mine to port, the rapid development of the Lake Superior ranges would have been impossible. It is not until the railroads had established themselves that the ranges became the most important iron-ore producing region in the world. Nine railroads are engaged in handling ore to shipside. All these railroads have special equipment for the carrying of ore and all operate their own docks at the respective ports which they serve.

Problems of Ore Transportation.—The transportation of the ore from mines to docks would be a comparatively simple operation if the grades of ore from various ranges, mines, and even shafts were similar, but the wide divergence in the chemical constituents of the ores makes sampling and mixing a necessary operation in order to bring the ore up to a certain grade. It seldom occurs that a train carries ore of such analysis that it may be run straight through from loading point to the docks without being split up for mixing. This, coupled with the fact that the ore vessels must be loaded promptly with a fixed tonnage and that the cargo loaded must be within a small fraction of 1 per cent of the analysis on which it was sold, does not allow much flexibility in the rail transportation of the ore.

As a result of this situation a well-defined plan of operation has been evolved. At the mine the cars, if loaded direct from the shaft or pit or from the stock pile, are taken to the mine siding, where a sample is taken from every ten cars. These samples, together with the numbers of the cars, are sent to the laboratory when the cars are made into a train and are started for their destination. The samples are analyzed and the results are entered on a "train sheet." The office then has the necessary data for each train which is ordinarily made up of 40 or 50 cars.

Daily reports of the vessels due within the ensuing 24 hours showing their tonnage capacity and the grades of the ore which they will load are received at the office. As the ore arrives it is laid out in the dock and numbered, a series of "ore blocks" containing tonnage of ore of a specific analysis. A record of each block with its position in the docks is kept, so that blocks can not be split up or altered. These blocks are prepared in such a manner that they will fill the requirements of the incoming vessel as to tonnage and grade of ore. Besides being segregated into Bessemer and non-Bessemer, the ores are divided according to the percentage of iron, silica, and manganese contents. Thus, if a certain grade of ore is desired, two or more blocks of different analyses may be mixed to bring the ore up or down to the required level. In order that this may be done with the least possible delay, there are kept on hand blocks of ore of varying grades to raise or lower the analysis of incoming blocks. Consequently, a vessel taking ore must load an entire block, as the mixing is a mathematical rather than a physical process.

The movement of ore over the lakes shows some interesting facts. The combined shipments from Duluth, Minn., and Superior, Wis., constitute by far the most important part of the ore movement. This tonnage is increased somewhat by shipments from two harbors, Marquette and Ashland. Thus, by the time the movement has approached the Saulte Ste. Marie locks it has reached its greatest volume. After passing the locks the movement is divided, about three-fourths proceeding down Lake Huron into Lake Erie and the remainder going into Lake Michigan destined for Milwaukee, Calumet, Indiana Harbor, and Gary. The Lake Michigan flow is augmented somewhat by ore from Escanaba. The ore passing through Lake Huron is destined to Point Edward and Detroit, Lake Huron ports, and Toledo, Huron, Lorain, Cleveland, Fairport, Ashtabula, Conneaut, Erie, Port Colborne, and Buffalo.

Method of Handling Ore at the Lower Lake Ports.—The ore vessels, as they enter, tie up along the face of the wharf on which are mounted unloading machines operating on tracks. These vessels are usually operated in batteries of from four to six machines. Vessels and machines are so designed as to enable an entire battery to operate on one vessel at the same time. While the operation of unloading is in process the ore is sampled in the holds of the vessel in order to determine its "test." As the ore is removed from the ship it is weighed and carried to railroad cars running under the unloading machines for direct shipment to interior points or to stock piles to the rear of the dock for future consumption. Some of the machines are designed to act as unloaders, distributors, and loaders, while others are used for unloading to railroad cars or stock pile only requiring bridge cranes in conjunction to distribute the ore uniformly over and to load cars from stock piles.

The smelters have so arranged their schedule of production that there is a steady flow of ore from ports to the interior, thus enabling them to secure as much ore as possible on the "direct ore" rate in addition to maintaining a constant supply of labor. In order that the flow of ore may be continued after the close of navigation, large storage areas at ship side are maintained.

There is no special rail equipment used in carrying ore from Lake Erie ports to smelters. Ordinary gondolas and hopper cars which are usually loaded direct from vessels during the season of navigation are used for this service. However, during slack periods and during the winter season ore is loaded from stock piles located on or near the docks. The largest flow between any two points is that between Conneaut and Pittsburgh. The rail shipments from Ashtabula are greater than those of any other port, but are widely distributed, principally to Pittsburgh, Youngstown, Johnstown, and Sharon. Cleveland consumes a large quantity of ore locally, but also ships to Youngstown, Sharon, Steubenville, Ironton, and Johnstown. Ore received at Buffalo is used for the most part locally, but large quantities also move to points in Pennsylvania, New York, and New Jersey.

Ownership of Ores.—The gradual realization, by the iron and steel producers, that the high-grade reserves of the Superior ore are limited, is bringing about a movement toward the purchase and consolidation of ore bodies by the steel companies with a view toward insuring their future supply. The estimates of reserves in Minnesota and Michigan by the state tax commissions discloses an almost unbroken downward trend of reserves in Minnesota for the past 14 years and in Michigan for the past seven years. The figures of the tax commission in Minnesota, where total reserves are taxed, are accepted as reasonably accurate inasmuch as the state has access to the records of the mining companies and has other means of determining the size and character of the ore bodies. In Michigan only developed reserves are taxed, but these also show a decline which may be indicative of the reserve situation. Along with the depletion of reserves is the factor of lowering iron content in the ore produced. This is reflected in the installation of beneficiation plants and a study of the treatment of high silica ores.[8]

THE SOUTHEASTERN ORES[9]

The ores of southeastern United States consist of a series of deposits extending from New Jersey and Pennsylvania through Maryland, Virginia, North Carolina, Tennessee, Kentucky, Georgia and Alabama. The proximity in this region of iron ore, coal limestone, and dolomite, all of which are essential to iron making, has had a great influence on the development and continuation of the industry there. The total reserve of merchantable ore probably exceeds that of the Superior district, but the geologic relations of the ore are such that the annual tonnage output cannot equal that of the open pit mines of the lake ranges. With a few unimportant exceptions, the southern ores are non-Bessemer.

Types of Ore.—Four types of ore are found in the southern ore fields. They are hematite, or red and gray ore; limonite, or brown ore; magnetite, or magnetic ore; and siderite, or carbonate ore. The most valuable deposits of hematite in the South are the Clinton ores that crop out at points in west central Virginia and almost continuously from Big Stone Gap, Va., southwestward along the base of the Cumberland

[8] Hain, A. J., Concentration in Ore and Ownership is Trend at Iron Mines, Iron Trade Review, Vol. 84, No. 1, January 3, 1929, pp. 36–40.

[9] Burchard, E. F., Alabama Ores Equal Lake Supply, Iron Age, Vol. 119, No. 12, pp. 847–850, March 24, 1927.

escarpment through eastern Tennessee and northwestern Georgia and terminate in the great deposits of the Birmingham district in Alabama.

Deposits of brown ore are common, particularly in valleys underlain by limestone and in the clays and sands of the Coastal Plain. Some of the best-known deposits are in Virginia, Tennessee, Georgia, Alabama, and northeastern Texas. Magnetite is found in commercial quantities in the Appalachian region of Virginia, North Carolina, and eastern Tennessee, and in the Piedmont region of Virginia and North Carolina, and there is a deposit in central Texas.

The Clinton Iron Ores.—The red, or Clinton, hematites are, by far, the most important of the commercial ores of the southern district. The tonnages run up into thousands of millions, the iron content ranges from 33 per cent to 40 per cent, they are very uniform in character and composition, and are cheaply mined. This type of ore is not confined to the southern section of the United States, but has been known and worked in New York, Wisconsin, and Nova Scotia, while the ores of Newfoundland and Lorraine-Luxemburg districts are closely similar in type.

The Birmingham District.—Birmingham, Alabama, the greatest iron center in the South, is second in rank in ore production in the United States. It compares favorably with Pittsburgh, Youngstown, and Chicago and may outlive them as a metallurgical center. The Birmingham district is an elliptical area about 75 miles long and about 40 miles wide. It includes extensive deposits of red hematite, large though less extensive deposits of brown and gray iron ores, and enormous areas of coking coal and fluxing dolomites and limestones. The city of Birmingham is flanked on the northwest by the noted Warrior coal field and on the southeast by the Cahaba coal field. Near at hand is Red Mountain, the source of the red iron ore. The Birmingham district ranks second to the Lake Superior district in iron ore production. In 1927 its output constituted more than 10 per cent of the total for the United States and exceeded that of any of the Lake Superior iron ranges except the Mesabi.

The Chattanooga District.—The district of which Chattanooga is the center comprises eastern Tennessee, northeastern Alabama, and northwestern Georgia. Chattanooga occupies an exceptionally advantageous position for iron and steel manufacturing. The bedded red hematite tributary to its blast furnaces underlies parts of the great plateau areas, such as the Cumberland Plateau, Walden Ridge, Sand Mountain, Lookout Mountain, and Pigeon Mountain, and crops out in the bordering valleys. The outcrops of bedded ore in the three states aggregate more than 200 linear miles. Blast furnaces are located at

Rockwood, Cardiff, and La Follette, Tenn., and Attalla and Gadsen, Ala., the output of which goes to foundries and other establishments in Chattanooga. Coal for the furnaces in this district is mined within a short distance, and at Rockwood, the iron ore, coal, and limestone are situated close together.

Future of the Iron Industry in the South.—The question of how long the Birmingham district may continue to mine iron ore and coal and to make iron and steel is of interest to the industry at large as well as locally. That the Birmingham district may prove to be the longest-lived iron mining district in the United States is based on the fact that since the ore is below the surface and has to be mined by underground methods and hauled out little by little the production can never be as rapid as that in the Lake Superior district where ore is dug on an enormous scale by hundreds of steam shovels and dumped directly into railroad cars within the open-pit mines. While the ore reserves in the two districts may amount to about the same quantity, possibly two billion tons, the output in the Superior district is, at present, ten times as great. Moreover, in times of emergency, as in the World War, the output from the open-pit lake mines can be expanded rapidly, while that of the Alabama mines is strictly limited by physical conditions. At the present rate of production the iron mines near Birmingham should last over 300 years whereas the exhaustion of the high-grade lake ores now in sight is expected in about 30 years. These figures may be altered by other circumstances, such as changes in the rates of production and consumption, the discovery of new ore bodies, improved methods of saving, clearing and utilizing low-grade ores, and the use of scrap metal.

Other Ore Deposits of the United States.—Iron deposits exist in considerable quantities in the northeastern states and in the states of the Rocky Mountain region. Some ore is mined for local consumption, notably in New Jersey, New York, Missouri, New Mexico, Utah, and Wyoming, but the aggregate compared with Lake or Alabama districts is small.

Foreign Iron Ore Available to American Iron Industry.—The rapid utilization of the high-grade domestic ores is causing the iron industry to look toward foreign sources of supply. While the American tonnages are enormous and could, if need be, supply domestic requirements for decades to come, they have certain characteristics which may make them less desirable than some of the foreign ore bodies. The low grade of much of the ore in the Lake district, together with the long distance from the Seaboard furnaces puts them in an unfavorable position in competition with foreign ores available by means of water transportation. The ores now imported into the United States come mainly from Chile, Cuba, Sweden, Spain, and French Africa. The aggregate imports amount to 2,500,000 tons, which is about 4 per cent of the domestic output. Other deposits of importance, from which supplies may be drawn in the future, are found in Newfoundland and Brazil.

Chile.—The iron ores of Chile consist chiefly of high-grade hematite, mostly Bessemer, averaging from 60 per cent to 65 per cent iron. The Bethlehem Steel Corporation is operating a property at Tofo which is said to contain at least 200 million tons of high-grade ore.

Cuba.—Cuba contains one of the largest reserves of iron ore, being estimated at over 3 billion tons. Practically all of this ore is brown hematite with a little magnetite and hematite in the Pinar del Rio field. The Oriente province, on the north coast of Cuba, contains the largest reserve, about 2½ billion tons of ore of over 40 per cent iron, but the moisture generally is very high, from 30 per cent to 35 per cent. The Bethlehem Steel Corporation owns more than two-thirds of the total reserve of Cuba, and most of the remainder is owned by the United States Steel Corporation and the Eastern Steel Company, so that practically all of the reserve is under American control.

Newfoundland.—Newfoundland contains one of the largest iron ore reserves in the world. This ore body lies near Beele Island, in the Wabana basin, a great part of it lying under Conception Bay. The ore is a fine-grained hematite, averaging from 48 per cent to 57 per cent iron. The recoverable ore is estimated at 4 billion tons. About half of the ore is owned by foreign corporations and will not be available to the United States.

Brazil.—Brazil has probably the largest undeveloped iron-ore reserve in the world, being estimated at 7½ billion tons of hematite, averaging over 60 per cent of iron. The principal deposits are in the state of Minas Geraes. The deposits are too far from the coast to be of any immediate commercial value, and, on account of the lack of fuel, there is practically no iron industry in Brazil. The reserves are owned by French, German, Brazilian, and American capital.[10]

Fluxes.—The process of smelting iron ore consists of separating the metal from the impurities with which it is physically or chemically combined. In this process two distinct steps are required, i.e., reducing the metal from its compounds and separating the mechanical mixture of molten metal from the impurities. Many of the materials are difficult to fuse and, to render them more fusible, a flux is used. Furthermore, some of the ingredients of the ore will, when fused, combine chem-

[10] Outlook for Foreign Iron Ore, Iron Age, Vol. 115, May 14, 1925, pp. 1423–1424.

ically with the molten metal and can be removed only by adding a material with which they will combine more readily than with the metal itself. This is the second function of a flux. Most of the ores of iron contain large quantities of silica, a highly infusible acid material and, in order to reduce its fusing temperature as well as to remove it from the iron, limestone or dolomite is added to the charge in the blast furnace. This latter material being basic in nature readily unites chemically with the acid silica to form a slag which floats on the molten iron. Limestone is widely distributed in nature and suitable deposits of this rock are nearly always found close to the iron-making centers. In the Birmingham district, for example, the iron ore, coking coal, and limestone outcrops are found in adjacent hills. An adequate supply of limestone presents no serious problems to the iron maker.

The growing importance of the open-hearth method of steel manufacture has brought another fluxing material into prominence, namely, fluorspar, or flourite. About 80 per cent of the total output of this mineral is used for open-hearth steel manufacture. The metallurgical use of fluorspar depends upon its relatively low melting point. It is added to the bath to make the slag more fluid so as to hasten the transfer of heat from the flame to the metal under the slag. It is also said to aid in the elimination of sulphur and phosphorus. (See Chapter on Industrial Minerals.)

Refractories.—Refractories play an important role in the iron and steel industry, in fact, no industrial process which requires high temperatures could be carried on without them. A refractory may be defined as any substance which is infusible at the highest temperatures it may be required to withstand in service. In addition to this it must be strong enough to stand up under the enormous pressures to which it is subjected. They form the chief material of which all furnaces and retaining vessels are made, as well as the flues and stakes through which the hot gases escape. The materials available for the manufacture of refractory bricks are clays, quartzite, magnesite, graphite, and chromite.

Pittsburgh occupies a dominant position in the manufacture of firebrick for all purposes. Its location near the natural gas area and the metallurgical industries make its position strategic with reference to raw materials and markets.

The Iron Industry in the United States.—Pig iron is the primary metal of the steel industry, the raw material out of which all other iron products as well as steel goods are formed. The output of pig iron is often regarded as a business barometer so sensitive is it to changes in the activities of the buyers. The basic importance of this metal, therefore, warrants a brief study of the location and organization of the iron-making industry.

Coking coal and iron ore are the foundation stones upon which the pig iron industry is erected. Both of the raw materials being bulky, it follows that the iron industry will locate where these are abundant. If, as is often the case, they are some distance apart, the iron ore will move to the coal fields rather than coke to iron ore. A variety of reasons, historical and economic, can be advanced to explain this. Pittsburgh, for example, the first important steel city, began its career in steel about the time that coke replaced anthracite as a fuel and the ore fields were shifting westward. Thus it was located on the finest bed of coking coal known and within reach of ores both from east and west.

Modern industrial progress has added cogent reasons for locating the smelters near the coal bed. In addition to the use of coke for smelting the iron itself, large quantities of fuel are required to convert pig iron into steel and for the production of power to motivate the mills. Moreover, the coke-making and iron-smelting industries afford a basis for many related industries such as glass making, the manufacture of chemicals and refractories, and the establishment of machine shops. The rule is not invariable, however, as will be noted in a study, in the following pages of the Gary, Cleveland, and Buffalo steel centers, and the erection of smelters in Duluth, Sparrows Point, and elsewhere.[11]

A supply of coking coal and suitable ores adjacent to each other or connected by cheap transportation routes is not the only requisite for a successful industry. Iron is used in large quantities for commodities other than those which are engaged in supplying man's elemental needs —food and housing, important as these are. Large tonnages are consumed by the automobile industry, industrial machine industry, railroads, shipbuilding, etc., the accompaniments of a highly industrialized civilization. A populous nation with a high material standard of living is necessary to furnish a market for the output of iron and steel. These conditions are fulfilled preeminently in the United States. The Pittsburgh coal bed, the most remarkable occurrence of high-volatile gas and coking coal in the world, is within easy reach, by water transportation, of the equally remarkable deposits of iron in the Mesabi and other ranges of the Lake Superior district. In the Birmingham district coal, iron and limestone are found in adjacent deposits. In Gary, Cleveland, and Buffalo, cheap transportation is a factor. Moreover, this country comprises the largest free trade industrial area in the world, occupied by a people of similar tastes and language affording opportunities for

[11] What Steel was Made and Where it Went in 1927, Iron Age, Vol. 121, No. 1, January 5, 1928, pp. 6, 7.

a large market. This combination of factors is surpassed nowhere in the world.

Let us consider the distribution of blast furnaces in the United

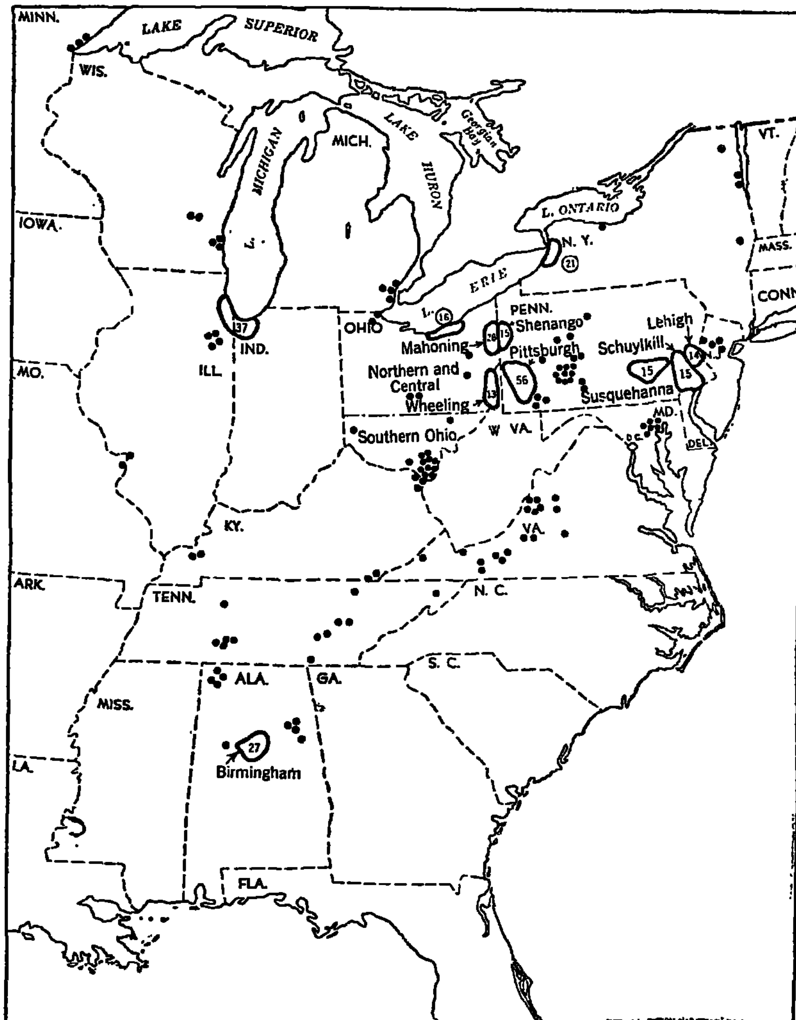

FIG. 7.—DISTRIBUTION OF BLAST FURNACES IN EASTERN UNITED STATES.

States in somewhat greater detail. Figure 7 shows the distribution in the year 1926. The dominance of Pittsburgh, Shenango, and Mahoning Valleys immediately is apparent. The districts owe much of their past and present importance to the Pittsburgh coal bed, the standard coal for the manufacture of beehive coke. As long as this method of coke manufacture dominated the industry this coal bed had no rivals. Hence coke manufacture was synonymous with the Pittsburgh district and, naturally, iron manufacture gravitated there. Iron ore, discovered on the western slope of the Allegheny mountains, supplied Pittsburgh for more than 50 years in the early days of its steel career. By 1865 there were 46 iron factories, 7 steel manufacturers, and 31 rolling mills in the city. Now the ores are obtained from the Superior district; the reserves of coal in the original Connellsville coking region are approaching exhaustion. But with the present supremacy of the by-product oven other and larger reserves of coal in this district have come into use for iron making.

To the east of the Main Pittsburgh area but really forming an eastern extension of it, lies the steel-producing district surrounding the town of Johnstown, on the Conemaugh River. Here are located the Cambria Steel Works. Lying to the southwest of the main district are the steel towns of Wheeling and Ironton, both of which may be regarded as minor extensions of the Pittsburgh district.

As we turn from the Pittsburgh and associated districts our attention is directed to the group of furnaces on the lake shore at Buffalo, Cleveland, and Gary. The lakeward movement of the iron industry is pronounced. Since 1901 the furnaces in the Buffalo district have increased from 4 to 21, have doubled in both Cleveland and the Gary-Chicago district, and are arising in Detroit. Altogether, there are nearly 90 furnaces. The westward movement of the market together with certain transportation advantages are factors in bringing about this change. In these Lake ports the ore from the Superior district is unloaded from ore carriers directly to the storage bins of the furnace plants, thereby saving the expense of an extra loading on railroad cars. Cleveland offers the best lowland route from Lake Erie to the Pittsburgh coal fields.[12]

On the Atlantic Seaboard the iron makers face several problems. The cost of raw materials is somewhat higher than in the interior districts. Competition with imported pig iron, mainly from India, is causing considerable concern among the manufacturers of the Schuylkill and Lebanon valleys. The isolated furnaces in Virginia appear to be declining while those at Sparrows Point, Md., are showing an increased output. With the exception of the Virginia furnaces, the Seaboard industry imports large quantities of foreign ore, mainly from

[12] Vander Blue, H. B., Changes in the Localization of the Pig Iron Industry, 1901–1926, Harvard Business Review, Vol. 4, No. 4, July, 1926, pp. 417–424.

Chile, Cuba, French Africa, Spain, and Sweden. A few new furnaces are being built where the facilities of obtaining cheap coke exist and where ore can be obtained by an all-water haul.[13]

The only important center in the South, Birmingham, Ala., like the Pittsburgh district, is dominated by one large coal bed, the Pratt seam of the Warrior coal field. On the average this seam is about 4 feet thick, but is not quite as uniform as the Pittsburgh bed. Two other coal beds, the Cahaba and the Coosa, lying further to the west, contain coal of coking grade in sufficient quantity to smelt the available iron ores for several generations to come.

Consolidations and mergers in the steel industry have progressed to a point where 90 per cent of the ingot capacity is controlled by ten companies. About 45 per cent of the entire capacity is controlled by the United States Steel Corporation, with the Bethlehem Steel Corporation next.

United States Steel Corporation	23,046,000
Bethlehem Steel Corporation	7,900,000
Youngstown-Inland Corporation	5,040,000
Jones and Laughlin Steel Corporation	3,000,000
Republic-Trumbell Companies	1,950,000
American Rolling Mills Company	1,750,000
Central Alloy Steel Corporation	1,400,000
Wheeling Steel Corporation	1,273,000
Colorado Fuel and Iron Company	1,138,000
Corrigan McKinney Steel Company	1,000,000
Total	47,497,000

THE IRON INDUSTRY IN FOREIGN COUNTRIES

A survey of the iron industry in foreign countries reveals a wide distribution of producers in Europe, Asia, Australia, and South America. Even Africa is represented among the countries producing the metal. Interest centers, however, upon Great Britain, Germany, and France as the dominant world iron and steel centers outside of the United States. The relative position of the various countries mentioned above is indicated in Table X.

This table represents over 90 per cent of the pig iron production of all Europe and about 80 per cent of the iron ore output. Part of the large iron ore production of France moves to Belgium and Germany. Additional amounts are received by the entire district from Sweden, Spain, and North Africa, mainly to Great Britain and Germany.

[13] Vander Blue, Homer B., and Crum, W. L., Pig-Iron Trend on the Atlantic Seaboard, Iron Age, July 23, 1925, pp. 210–212.

TABLE X *

EUROPEAN IRON ORE AND PIG IRON PRODUCTION, 1923–1927

Country	Pig Iron	Per Cent of Total	Iron Ore	Per Cent of Total
Germany	45,600,392	28.0	25,641,211	8.7
France	40,351,476	24.7	173,142,552	58.5
Great Britain	31,266,093	19.2	48,129,948	16.3
Belgium	14,654,164	9.0	602,690	0.2
Luxemburg	11,209,596	6.9	31,125,710	10.5
Russia	7,454,133	4.5	11,781,079	4.0
Sarre	7,326,224	4.4	....	....
Czechoslovakia	5,354,498	3.3	4,499,548	1.5

* Abstracted from Iron Ore in 1927, U. S. Bureau of Mines.

The commanding importance of these iron- and steel-producing nations in European, or even world political affairs, finds its present origin in the control of steel and coal. First in rank in the post-war industrial reconstruction is western Europe, i.e., the district including parts of France, Germany, Belgium, and Luxemburg.

The Franco-German Iron Industry.—The iron and steel industry of western continental Europe is built upon the coking coal deposits in the Ruhr Valley in Germany and the iron ores of Lorraine, together with shipments from Sweden, Spain, and North Africa. The Franco-German industrial district, together with its smaller associates, Belgium and Luxemburg, controls about 60 per cent of the iron and steel furnaces of Europe with annual products of 30 million tons. This remarkable concentration of industrial resources, no larger than the State of Vermont, nevertheless assures a permanent industrial, financial, and military supremacy for the countries concerned. Although the basic raw materials are located in a small geographic area, they are divided by international boundaries, as a consequence of which, the economic and political activities of the region are closely interwoven. Of these nations, Germany and France are mutually interdependent. Belgium and Luxemburg must import both coal and iron ore to keep their furnaces active. Two other countries, Sweden and Spain, have considerable reserves of iron but no coal. Hence they cannot develop extensive manufacturing industries, but are important to the Franco-German and British steel industries as contributors of one of the basic raw materials. Before we can appreciate the complexity of the industrial organization of the Franco-German district, it is necessary to survey in further detail the political distribution of the mineral resources.

With regard to the iron resources, the event of the World War has placed France first in Europe, if not in the world. For, in addition to gaining by conquest half of the largest of the ore fields, another of almost equal size had been developed previously on her own soil. In terms of reserve ore tonnage, France now has in the Lorraine basin some 5 billion tons of ore, capable of producing 2 billion tons of pig iron. In the Anjou-Normandy basin recent estimates suggest a total ore reserve of at least 2 billion to 3 billion tons of far higher grade than the Lorraine product, and capable of yielding between 1 and 1½ billion tons of pig metal.[14]

Germany, deprived of the Lorraine iron fields by the Treaty of Versailles, is subordinated to a minor position insofar as her supply of iron ore is concerned. She is rated as having 1.3 billion tons of actual ore with possible ores amounting to 2.9 billion tons additional.[15] In any event, Germany now depends upon imports for more than half of her ore requirements from Sweden, Spain, North Africa, and Newfoundland.

The other countries included in the Franco-German industrial district—Belgium and Luxemburg—possess only negligible quantities of ore. Their metallurgical industry depends upon imported ore and exports of iron and steel goods.

We now turn to the coal reserves. At the opening of the World War the German Empire was credited with possessing close to 60 per cent of the entire European coal reserves and some 30 per cent of the coal iron ore reserves. The war reduced the iron ore reserves sharply but did not seriously affect coal. The decrease in the latter was due to the temporary alienation of the Saar field and to permanent losses in Silesia. This leaves Germany with the Westphalian coal field, in the lower Rhine Basin, intact. The coking coal of this field is among the best in Europe. This fact, coupled with its geographic location with reference to the Lorraine ores on the one hand and to tidewater on the other, has made Westphalia not only the greatest coal-producing center of western Europe, but also the scene of the most extensive manufacture of iron and steel. The reserves in the Westphalian basin have been estimated at 213,566 million tons and probably 50 per cent of this is suitable for coking.[16] In this field the highest perfection has been obtained in coke manufacture with complete utilization of all by-products.

The Saar coal field, temporarily under French control, is located

[14] Eckel, E. C., Europe's Industrial and Political Future Pivots on Coal and Iron Ore, Iron Age, Vol. 124, No. 3, July 18, 1929, pp. 153–154.

[15] Commerce Reports, January 3, 1927, p. 16.

[16] Coal Resources of the World, International Geological Congress, Toronto, 1911.

directly south of the Westphalian coal field and near the eastern border of the Lorraine iron. In quantity and quality of coking coal, it is inferior to the coal from the Ruhr Valley, and does not play an important part in the metallurgical industry.

Other coal fields in Germany, west of the Rhine and in Silesia, do not enter into the metallurgical industry, either because of high mining costs, or inferior grade of coal.

Outside of Germany but within the industrial center, i.e., northern France, Belgium, and Luxemburg, the coal resources are very limited so that imports are necessary.

Upon these coal and iron resources pre-war Europe had built a closely integrated iron industry. The complexity of this organization is apparent when one considers the number of its component parts—iron mines, coal mines, transportation lines (water and rail), blast furnaces, steel plants, finishing plants, and factories using iron and steel products—all essential to the functioning of a productive industrial area. This vast economic unit, transcending international boundaries, overlaps Germany, France, Belgium and Luxemburg. It is the principal source of iron and steel goods for Europe and also exports these goods into the world's markets. Its successful operation depends upon peaceful relations among the countries concerned.

The disruptive consequences of the World War and the readjustments of international boundaries ensuing from the peace treaty destroyed the existing economic relationships. The old established metallurgical districts of Europe with their long-standing relationship to raw materials and markets were cut asunder by tariff boundaries. The political re-allocation of the iron ores and the coal fields, which left Germany with practically most of the coal and France with the major part of the iron is bringing about a realignment of the component elements of the iron and steel "units." Germany is attempting to rehabilitate its metal industries by imports from Sweden and other countries previously mentioned, while decreasing its dependence upon the Lorraine. The Swedish mines, for example, are supplying about 60 per cent of Germany's imports.

The French industry is also being modified. The close dependence of France upon Ruhr coal in the pre-war period continues, but there is a noticeable increase in coal imports from Great Britain, part of which enters the iron and steel industry. France will always depend upon imported coal to satisfy her needs. Whether those imports will come mainly from Germany, or to an increasing degree from England can be determined only in the future. Conditions in the two coal producing countries seem to favor Germany.

The British Steel Industry.—Fifty years ago Great Britain was still the leading producer, as she had been for a century before that, of coal, pig iron, and steel, and by far the leading exporter of each of these basic industrial products. The location of almost all of the coal fields and most of the iron works at or near the coast, the preeminence of the British merchant marine and the existence of trading outlets in South America and the colonies, assured for Great Britain a large market.

Britain is well supplied with iron ore, the reserves being estimated between two and three billion tons. These ores, however, are with minor exceptions low in grade, so that the domestic output must be supplemented by importations from Sweden, Spain, and elsewhere.

The industry has suffered a depression since the World War, due to the expansion of facilities beyond peacetime needs and the increasing competition of continental producers. Since Britain's economic well-being depends so largely upon foreign trade, the status of steel exports is of vital interest to the nation. While the financial and political power of the British Empire has not been seriously impaired by the World War, the metallurgical industry in England faces a critical and dubious future. Imports of iron and steel have increased while exports show a decline. The weak points of the British situation lie in the fact that practically all foods and raw materials have to be imported from high cost countries; so that living costs and wages will normally be above French or German levels. Unless the declining trend of steel and coal production can be arrested and a high level of export trade be re-established, the imperial and financial power of the Empire will ebb with the decline of the coal and iron trade.

In Central and Eastern Europe there are only three countries that have the potentialities of a limited iron and steel industry. First among these is Russia, whose coal and iron reserves in the Donetz basin present possibilities of becoming an important mining and manufacturing center. Output of both iron ore and pig iron are increasing rapidly in this country, viz.:

	Pig Iron	Iron Ore
1923	312,076	414,423
1924	669,642	932,969
1925	1,308,067	2,201,706
1926	2,217,348	3,415,278
1927	2,947,000	4,816,703

This nation with a population of 150 million, awaiting an era of industrialization, offers a potentially large market for manufactured goods.

Poland, through post-war boundary readjustments, has secured coal in excess of her manufacturing needs. Czechoslovakia has sufficient coal to be important, enough iron ore, and finishing plants on a relatively large scale so that the domestic market can be supplied without imports.

The location of the iron and steel industry has a very important bearing on competitive conditions there. During the World War, the productive capacity in all of the western European nations was expanded. The post-war period was accompanied by a decline in demand for steel together with an expansion of capacity in Germany to replace the furnaces taken over by the French. The result was overproduction, ruinous competition, dumping. Out of this condition arose the formation, on September 30, 1926, of the International Steel Entente. The original signatories represented the steel industries of Belgium, France, Germany, Luxemburg, and the Saar district. Three months later the steel producers of Czechoslovakia, Austria, and Hungary also became members of the Entente on a joint basis.[17]

The cartel, as first organized, included the crude steel producers only, and allocation of markets was confined to unfinished steel. However, fluctuations in world trade conditions, entirely beyond the control of the steel industry, demonstrated the inability of the crude steel organization to bring about the desired goal of higher export prices. Accordingly, the cartel was reorganized to include the major steel products with the hope of correcting some of the drawbacks of the crude steel cartel. That this extension of the cartel's scope of activities failed to iron out the defects satisfactorily is indicated by the fact that repeated negotiations were held by the member countries. A world-wide depression in the steel industry in late 1929 and early 1930 necessitated a revision of the quotas for each country, and the formulation and perfection of plans for the 1930 foreign trade in steel. Hence in March, 1930, a meeting of the cartel members was called, where plans were laid for a world trade campaign to follow the expected revival of the steel markets after 1930. Five international sales offices, through which the cartel will sell its products to the world, were organized.

This plan signalized a degree of European industrial cooperation which clearly points to an economic unification of Europe. In the first place it means that four producing nations—Germany, France, Belgium, and Luxemburg—have succeeded in bringing all the steel makers into a

[17] Balfour, Arthur, Effect of the World War on the Iron and Steel Business, Trans. Amer. Soc., Steel Treating, Vol. VIII, No. 5, November, 1925; Leith, C. K., The World Iron and Steel Situation and Its Bearing on the French Occupation of the Ruhr, Foreign Affairs, June 15, 1923, Vol. 1, No. 4; Tower, Walter S., The New Steel Cartel, Foreign Affairs, January, 1927, Vol. 5, No. 2, pp. 249–266.

common accord. Second, it means that a domestic agreement having been accomplished, the producers have voted to pool their foreign sales efforts and to operate in the future through the cartel's sales offices. Anyone who is in touch with the European situation will appreciate the monumental task undertaken by the constructors of the cartel and the extent of their success.

Difficulties have been encountered from the first days of the cartel's existence, but fundamental unity is now regarded as firmly established. This, in the opinion of Europeans, is proof that when vital industrial issues are at stake, Europe can and will unite.

The aims of the continental steel cartel touch upon a problem which is not confined to Europe but is world wide in its aspects. The outstanding fact in modern industry is the definite trend toward large scale production units, world-wide trade, intensified competition. The industrial districts of the world are engaging in a battle for markets that is destined to reach the farthest corners of the globe. Whether the coming competition will be ruthless, destructive, and provocative of ill-will among the industrial powers, especially as between Europe and the United States, or, whether an allocation of markets will be worked out by an international organization, in which all important steel producers are included, is a matter of momentous importance.

The possibility of American cooperation with the cartel has been the subject of conversations between the cartel members and representatives of the American steel companies, although, as yet, nothing of a definite character has been accomplished. Business observers, in summing up the advantages of American cooperation with the cartel—membership is ruled out because of the American anti-trust laws—have come to the conclusion that the benefits would be fairly evenly distributed. If the plans approved in March, 1929, are carried out, the cartel will prove itself to be a disturbing competitor in many markets where the Americans count upon augmenting their exports, notably in South America and the Far East. Through lower production costs and the advantages of unity of action, the cartel will give the Americans the hardest kind of competition.

On the other hand, the European steel makers, realizing that America's great steel industry has until now disposed of most of its production in the domestic market, are afraid that depression at home might encourage the Americans to concentrate on Europe. Thus they would welcome an agreement by which the Americans would restrict their activity over here to its present volume, in return for which the cartel might consent to a "gentleman's" agreement covering South America and the Far East.

CHAPTER XVI

THE ALLOYING METALS OF STEEL

Alloy Steels.—Certain elements or metals are capable of purifying steel, and when alloyed therewith, of giving it certain desirable qualities. Eight or nine of these metals are so used as alloys. They are manganese, chromium, nickel, tungsten, molybdenum, vanadium, zirconium, titanium, and silicon. Alloy steels vary in character and value. The principal ones are the following:

(1) Nickel steel, with a nickel content from 2 per cent to 4 per cent, used mainly in the manufacture of high-class structural steel, forgings, and plates.

(2) Chrome nickel steel, with a chromium content of $1\frac{1}{2}$ per cent employed in the manufacture of forgings like axles.

(3) Tungsten steel, ordinarily containing either 14 per cent or 18 per cent tungsten, used in the manufacture of high-speed tool steels, and, with a smaller percentage of tungsten, in the manufacture of other tools.

(4) Vanadium steel, containing less than 1 per cent of vanadium, for automobile parts subject to repeated stresses.

(5) Molybdenum steel, used for the same purposes as vanadium steel.

(6) Chrome steel, used in small quantities in the manufacture of ball bearings.

(7) Manganese steel, employed in the making of rolls and rails and other products subject to abrasion.

In addition to these steels there are copper steels which resist corrosion, silicon steel employed in the manufacture of springs, electric transformers, etc., and zirconium steel which may come into competition with vanadium steel.

Considerable attention is being given to the production of "stainless" cutlery steel, containing 12 per cent of chromium, and its extension to other uses to prevent destruction by rust.

These metals, because of their importance in steel manufacture, an importance that is altogether out of proportion to their volume, must concern every nation possessing an iron and steel industry. Nature has not placed these metals near the steel-making centers, or within the boundaries of the industrial nations. Each of the metals may be regarded, in a sense, as one of the keys of the steel industry and, as such, their political and commercial control becomes a matter of international interest. With the exception of molybdenum and silica the United States is not endowed with an abundant supply of any of these metals. The most important of the steel-making countries, it depends upon foreign countries for the supply of these key metals. In the discussion that follows, the ferro-alloys will be studied from the point of view of the interest of domestic consumers omitting any world relations not relevant to the domestic situation.

MANGANESE

Manganese deserves first place in the order of importance of the steel-alloying metals. Roughly 92 per cent of the consumption of this metal enters into steel manufacture, for which it may be regarded as indispensable. In iron and steel production it serves two purposes: First, as an aid in the manufacturing process, and second, as an alloy to impart special physical properties to the finished steel. In the manufacturing process it is used as a deoxidizer, and to a lesser extent, as a desulphurizer. In this role it removes oxygen which is combined with iron, or prevents the oxidation of iron by the formation of manganese dioxide. This action on the part of manganese prevents "red shortness" and "cold shortness" and improves the rolling and forging qualities of steel.

Now, sulphide of iron, like the oxide, makes steel red short and manganese again aids in the removal of this deleterious element. Manganese, added to the molten pig iron, preparatory to steel making, combines with sulphur which floats to the surface, in part, to mix with the slag. The sulphur remaining in the iron in this form is comparatively innocuous. Moreover, the combination of manganese with oxygen results in the production of steel commercially free from blow-holes, and makes it possible subsequently to treat the steel, after casting, without causing breakage.

In addition to deoxidizing and desulphurizing properties, manganese also confers upon steel valuable physical properties of its own. It increases the strength without reducing seriously the ductility of steel. In this respect it gives results much like nickel and with less cost.[1]

When manganese is added in quantities varying from 11 per cent to 14 per cent, the steel becomes very tough and strong. When toughened

[1] Boylston, H. M., The Importance of Manganese in the Steel Industry, Trans. American Society of Mining and Metallurgical Engineers, Vol. 75, pp. 397–402.

with water manganese steel is practically non-magnetic and is a much poorer conductor of heat and electricity than ordinary steel. Because of these distinctive characteristics this steel has been found peculiarly serviceable for frogs, switches, crossings, curved rails, and crossovers for railroads and street car tracts. In railroad service, manganese steel curved rails will last five or six times as long as ordinary steel rails. In mining, milling, rock crushing, digging, and dredging machines, it is used to form those parts subject to abrasion and wear. Its non-magnetic properties make it useful in certain classes of electrical work.[2]

In addition to its use in the steel industry, manganese is also employed in the manufacture of dry batteries, a decolorizer of glass, a drier of paints and varnishes, and in the manufacture of disinfectants and coloring materials.

For use in the manufacture of steel, manganese is prepared into the alloys ferromanganese and spiegeleisen, each being an alloy of manganese with iron.[3] A small contribution of the alloy is made through manganiferous pig iron, a special pig containing from 4 to 10 per cent manganese.

Occurrences.—Manganese is not found in the metallic state in nature; it occurs only in combination with other elements as an oxide, a carbonate, or a silicate, oxides being the most common. The ores of manganese are widely distributed in nature but only in a few localities do they occur in large tonnages of high grade ore. These are the deposits in India, Brazil, the Caucasus, and the Gold Coast of Africa. Deposits of secondary importance are located in Czechoslovakia, Chile, Cuba, Spain, and China, while minor deposits exist in 24 other countries. About 80 per cent of the world's output comes from the four leading countries noted above and nearly 75 per cent is consumed by the United States, Germany, France, and England.

Russia.—Manganese occurs in many places in Russia. The developed deposits consist of those of Nikopol in southeastern Russia, north of the Caucasus, and the Tchiaturi deposit in the Province of Kutais, Republic of Georgia, south of the Caucasus. The former has been estimated to contain upwards of 10 million tons of commercial high-grade ore. The Tchiaturi deposit may be classed as the largest single

[2] Camp, J. M., The Making, Shaping, and Treating of Steel, 4th Ed., 1927, Carnegie Steel Company.

[3] *Ferromanganese.*—There are two grades of ferromanganese, known as A and B grade. Grade A contains 95 per cent of manganese and is used for special purposes and in very small amounts only. Grade B is the commercial "ferro" of the steelmaker. Its standard content of manganese ranges from 78 to 82 per cent.

Spiegeleisen.—This alloy has a wide range in manganese content, namely, from 15 to 35 per cent; standard is 18 to 22 per cent.

deposit now known; it covers some 22 square miles and estimates of the total commercial ore range from 44 to 200 million tons. Because of quality, quantity, accessibility, and cheapness of mining the Tchiaturi deposit will for many years be one of the controlling factors in the world's manganese situation.[4]

India.—The number of known deposits of India exceeds several hundred. At present some 50 to 75 deposits are contributing to an annual output of roughly 660,000 tons, 80 per cent of which comes from the Central Provinces. The largest deposit in that district is a bed 45 to 50 feet thick which has been explored in length for a mile and three-quarters, and has yielded more than 1,300,000 tons of 50 per cent ore. The Geological Survey of India estimates that an annual production of 600,000 tons can be maintained upwards of 40 years.[5]

Brazil.—The principal sources of manganese in Brazil are the Nazareth district in the State of Bahia and the LaFayette district some 300 miles north and west of Rio Janeiro in the state of Minas Geraes. The largest developed group of deposits there is known as the Morro de Mina, and is estimated to contain at least 9 billion tons.[6] Many undeveloped deposits containing large amounts of high-grade ore are at present inaccessible. The ore carries 40 per cent to 49 per cent of manganese. Mining costs are higher than in Russia or India. The largest developed deposit is owned by the United States Steel Corporation.

Gold Coast.—The Gold Coast contains several deposits of manganese which, with the exception of the Dagwin concessions, lie about 300 miles from tidewater. The only developed mine, the Dagwin, lies 35 miles from tidewater. This deposit contains about 15 million tons of ore of a grade comparable to the Georgian ore.[7]

Domestic Manganese Supplies.—In the United States the production of manganese, except during a few years prior to the introduction of the Bessemer process of making steel, has never been able to satisfy the domestic demand. The occurrences of manganese in this country are, broadly speaking, well known, and if past history of the mining

[4] Furness, J. W., The Manganese Situation from a Domestic Standpoint, Bureau of Mines Circular No. 6034, April, 1927, p. 12; Svironoff, V. C., Potentialities of Georgian Manganese, Eng. Min. Jour., Vol. 120, Oct. 31, 1925, p. 690; Spurr, J. E., Russian Manganese Concessions, Foreign Affairs, April, 1927, Vol. 5, No. 3, pp. 506, 507.

[5] Banerjea, S. S., Manganese and Bauxite in India, Eng. Min. Jour., Vol. 122, August 14, 1926, p. 254.

[6] Furness, J. W., The Manganese Situation from a Domestic Standpoint, Bureau of Mines Circular, No. 6034, April, 1927.

[7] Kitson, A. E., Geology of the Manganese Ore Deposits of the Gold Coast, Africa. Trans. A.I.M.E., Vol. 75, pp. 372–396.

of this metal is taken to indicate the trend of the future, the United States does not possess a supply that can meet its demands. An exhaustive study of possible manganese production in this country was made by a committee of the two important mining societies.[8] This group reviewed very carefully the production of this metal under the urge of high prices under war conditions and, with this war experience before them, attempted to estimate reserves and future production.

In this connection, the question arises: What constitutes an ore reserve? "In the ordinary sense, ore is metalliferous material which can be produced and marketed at a profit. This means that with changing conditions as to cost and price, the measure of ore reserves must likewise change, there being a constant shifting back and forth across the borderline between ore and waste."[9] A high price, as may be expected under war conditions, would immediately bring into the class of ores materials hitherto regarded as waste, and upon such a set of conditions the war reserves of manganese were estimated by the committee. For purposes of establishing a definite basis of measurement a price of $50 per ton of 50 per cent base manganese was assumed with an annual steel production of 50 million tons. Under present metallurgical practices this steel would require:

200,000 tons of manganese in the form of ferromanganese.
45,000 tons of manganese in the form of spiegel.
40,000 tons in the form of high manganese pig iron.

The domestic resources, measured by the amounts that would be brought out at a price of $50 were estimated as:

433,000 tons of manganese in the form of ferromanganese.
1,480,000 tons of manganese in the form of spiegel.
1,500,000 tons of manganese in the form of high manganese pig.

Extremely limited as these reserves appeared to be (not much more than 2 years' supply), an even more serious consideration from the standpoint of supplying the needs of the steel industry from domestic resources during a period of national emergency is the expected *rate of production*. A review of past records of production, under the stimulus of high prices, convinced the committee that domestic needs could only be supplied in part, and that after three years of increasing production, the curve of output would decline unless further price stimuli were applied.

[8] International Control of Minerals. Published jointly by the A.I.M.E. and the Mining and Metallurgical Society of America. Section on Manganese, pp. 51–86.

[9] International Control of Minerals, p. 60.

The committee took cognizance of the existing high manganese tariff as an inducement towards establishing a domestic manganese industry and made the following comments:

There are those who believe and maintain that the domestic manganese reserves of the United States are very large, many times the figures herewith presented by your committee. Actuated by this belief, it is the opinion of these people that a domestic manganese industry should be created and fostered by artificial means—by tariffs or bonuses—so that an emergency may find it actively functioning and prepared to meet any requirements. Your committee cannot agree with this opinion, simply because it does not find the large reserves. Effective artificial stimulation of domestic manganese production would merely serve to deplete the already limited reserves, very possibly to the point where the next emergency would find the country practically bare. The tariff enacted in 1922 has not been effective except in the direction of maintaining a small production of chemical ore from Montana. This is not serious at present from the point of view of depletion, but might become so, since Montana is the only present known domestic source of this class of ore of any importance. Otherwise relatively no true ferrograde production has resulted from the tariff. Moderate amounts of lower-grade ores are being produced in Arkansas and Colorado, apparently going to blast-furnaces for the double purpose of supplying manganese to the pig-iron and helping to flux the charge. A considerably higher tariff would in fact be needed to create a domestic ferrograde manganese mining industry.

An interesting opinion held by some that, by artificially boosting the cost of ferro, changes in metallurgical practice will be stimulated which will ultimately lead to the substantial elimination of ferro and the substitution of spiegel and high-manganese-pig—materials which can be made from the leaner and far more abundant domestic ores. The hope is thus entertained that the United States will become largely independent of foreign sources and so be prepared for another war emergency. There is some ground for this expectation, but, in the opinion of your committee, only to a strictly limited extent. To this extent, in fact, your committee has discounted its estimate of requirements; with the result that it finds that over 70 per cent of the manganese must still in all probability be supplied in ferro form. To go beyond this would require measures unwarranted in times of peace, and involving risk of seriously disturbing production in times of war.[10]

In a paper presented before the American Institute of Mining and Metallurgical Engineers, J. V. W. Reynders agreed substantially with the finding of the Manganese committee and stated that the present tariff was unjustifiable. This report elicited several replies in which his

[10] International Control of Minerals. Published jointly by the American Institute of Mining and Metallurgical Engineers and the Mining and Metallurgical Society of New York, 1925. See also: Joseph, T. L., Barrett, E. P., and Wood, C. E., Minnesota Manganiferous Iron Ores in Relation to the Iron and Steel Industry, Trans. A.I.M.E., Vol. 75, pp. 292–345; Zapffe, C., Reserves of Lake Superior Manganiferous Iron Ores, Trans. A.I.M.E., Vol. 75, pp. 346–371; Brown, R. H., Domestic Manganese and the Tariff, Eng. Min. Jour., Vol. 124, No. 11, September 10, 1927, p. 404; Reynders, J. V. W., Repeal the Manganese Ore Duty, Iron Age, Vol. 119, No. 16, April 21, 1927, pp. 1147–1149.

and the committee's findings were disputed, the controversy centering largely around the possibility of developing, under tariff protection, the metallurgy of manganese so as to make possible the manufacture of ferromanganese from low-grade manganese deposits of which there is an abundance.[11]

The controversy over the tariff policy was renewed in the summer of 1929 when hearings on the Hawley-Smoot tariff bill were being held. Steel manufacturers asked that the duty be removed entirely. Domestic manganese producers asked for an increase in the existing tariff schedule. The steel interests held to the same view previously expressed by the Committee of the mining societies that there are no high-grade deposits of manganese in the United States, that promises of the domestic producers to develop processes for the manufacture of high-grade material from low-grade ores on a commercial and reasonable price basis had not been fulfilled and give no indication of being fulfilled, and that the duty is an unnecessary burden on consumers.

In direct contrast, domestic manganese producers maintained that processes for the beneficiation of low-grade ores for the production of standard ferromanganese on a reasonable price basis are being developed, enormous deposits of material which can be treated for this purpose exist and have been discovered, and some plants now are making high-grade ore, and if given further protection, the domestic producers will be able to supply the domestic requirements satisfactorily.[12]

Steel makers asked for the conservation of such supplies as exist in case of necessity in times of emergency. Manganese interests on the other hand asked for added protection in order to develop an industry which will be able to supply necessary requirements in times of emergency.

In view of the fact that manganese is of strategic importance as a war mineral—one of the most important war minerals not produced in the United States—the possibility of creating a serious shortage in an emergency through curtailment or cessation of imports from foreign sources, is of more than usual interest. The two parties in the tariff controversy would provide for such a contingency by diametrically opposed policies. A proposal by the Committee of the mining societies offers a

[11] See Trans. A.I.M.E., Vol. 75, pp. 272–291, for Mr. Reynders' paper and the discussions following it.

[12] Zapffe, Carl, Why Domestic Manganese Should Be Adequately Protected, Eng. Min. Jour., Vol. 127, No. 10, March 9, 1929, pp. 389–391; Joseph, T. L., Barrett, E. P., and Wood, C. E., Fostering a Domestic Mining Industry, Eng. Min. Jour., Vol. 127, No. 8, February 23, 1929, pp. 309–313; Zapffe, Carl, Leaching Manganese by the Bradley Process from Siliceous Iron Ores of Minnesota, Eng. Min. Jour., Vol. 127, No. 36, pp. 1039–1041.

plan which would ensure a supply without tariff protection and conserve the domestic supplies when needed. Briefly, their recommendations provide for the purchase, by the government, of ample supplies of manganese ores to be held in stock at suitable localities for tiding over a war emergency. At the same time a perpetual inventory of domestic reserves, rate of possible production, and total amounts that could be looked for, would be maintained. This proposal would have the double intent of giving the steel industry the advantage of cheaper foreign ores and conserving the limited domestic supply for emergencies only.[13]

During the past few years the control exercised by nationals of the United States over foreign sources of manganese through companies whose operations they have financed has led to a rather rapid elimination of what may be termed the "free market." This policy has been followed in part by other nations—for example, the consolidation of some of the English manufacturers of ferromanganese with the Central Provinces Mining Co. (Ltd.), of India—and in consequence the production from sources of manganese that are without consumer affiliations has been in part, at least, restricted. The present control of the Tchiaturi deposit by lease; the possible control by contracts for purchase of ore of the Dagwin deposits of the Gold Coast by nationals of the United States; the ownership of Brazilian deposits by the United States Steel Corporation; the acquisition of the Postmasburg deposits of South Africa by an American corporation; and the German control of the Nikopol deposits of the Ukraine, have led to the tendency by the nationals of these groups to utilize ores in which they were interested.

Chromium.—The development of alloy steels possessing special qualities of hardness, toughness, strength and resistance to wear or corrosion which steel alone does not possess underlies much of the mechanical progress of recent years. Among the various alloying metals chromium is one of the most important, used either alone or in varying combinations with such other metals as nickel, tungsten or vanadium. The addition of a small percentage of chromium to steel gives the finished product intense hardness combined with toughness. Ordinary chrome steel contains about 2 per cent chromium. In the process of manufacture the chromium is added to the steel bath in the form of ferrochrome, alloy containing about 70 per cent chromium and the remainder iron and carbon. This type of steel can be bent cold, and can be welded to iron to form either a surface or a core that is extremely resistant to the attack of even the finest drilling tools. Its uses are many including the manufacture of axles, springs, parts of gun

[13] International Control of Minerals, 1925, pp. 85, 86.

carriages, automobiles, steel for safes, tires, cutlery steel, projectiles and armor plate. Steels intended to resist abrasive action are alloyed with vanadium, nickel, tungsten and manganese in addition to chromium.

The addition of somewhat larger percentages of chromium to steel provides an alloy that resists corrosion, thus steel containing 10 per cent to 15 per cent is known popularly as stainless steel, which has already become familiar in household cutlery. It promises to have a broadening field of employment wherever steel is subjected to unusually corrosive conditions. Engine valves, marine equipment, builders' hardware, annealing boxes and ovens, chemical manufacturing equipment afford illustrations of the industrial applications of various chromium alloys.

In the chemical industries in the form of chromite, this metal is of great importance. Chrome pigments—yellow, green and red—are widely used. In the dye industry, the soluble chromates and bichromates are used as mordants. They are also used in the tanning of chrome leathers, and in the bleaching of fats and oils. In the ceramic industry the chromic acids and the bichromates are used to color pottery. The most important use of chromite is that of a refractory brick in the open-hearth steel furnace.

Of the newer uses of chromium, one of the most interesting is for coating metals. In this country and abroad the electrolytic plating of various metals with chromium is now on a commercial basis. The coating is hard and white, resembling platinum; it resists the action of ammonia fumes, hydrogen sulphide, and nitric acid, and is not attacked by molten zinc, tin, or brass. It is said that chromium adheres more closely to the metal on which it is placed than does nickel, and a brilliant finish can be obtained without polishing. It is being used to an increasing extent for automobile finishing and for plating bearings. As chromium is not corroded by vegetable and fruit acids, it may possibly supplant tin for some purposes. The research work that has been done on chromium alloys for resisting corrosion and high temperatures bids fair to revolutionize some of the older industrial processes and to make new ones possible.[14]

Substitutes.—For the manufacture of certain steels there is no known substitute for chromium. In tanning also, no satisfactory sub-

[14] Bellis, C. B., Importance of Chromium to the Engineer, Chem. and Met., Vol. 30, January 28, 1924, pp. 149–151; Fink, C. G., Chromium—Its Properties and Uses, Soc. Auto. Eng. Jour., Vol. 20, January, 1927, pp. 157–159; Mitchell, W. M., Chromium and Its Relation to Industry, Iron Age, Vol. 113, April 3, 1924, pp. 1011–1012; Primrose, H. S., Manufacture and Use of Stainless Steel, Iron Age, February 12, 1925.

stitute has been found. For pigments, chromates may be replaced but, as a rule the substitutes are more expensive. In steel furnaces operated at lower temperatures, chromite bricks may be replaced by magnesite bricks.

Occurrence.—Chromium occurs in nature as chromite, a mineral composed of chromium, iron, and oxygen. Deposits of this mineral in varying degrees of richness are found in many parts of the world, but the ore bodies of major importance appear to be located in the eastern hemisphere. Present knowledge indicates that the world's major resources of chromite are in South Africa (southern Rhodesia), New Caledonia, and western Asia Minor (Anatolia). In addition to the high-grade ore found in the countries mentioned, a large potential reserve of what is known as chromiferous iron ore is found in Cuba, Celebes, the Gold Coast and Greece. These chromiferous iron ores contain a fraction of 1 per cent to 3 per cent chromium, associated with a small percentage of nickel. The Cuban deposits in the district of Mayari, have been estimated to contain upwards of 2 billion tons of such ore and those of the Celebes more than 1 billion, 4 hundred million tons.

The reserves of Rhodesia seem ample to supply the world's present needs for many years. They are probably of greater commercial importance and are more extensive than any others now known. More than 130 lenses of chromite ores have been mapped. At the end of 1925 Rhodesia had produced 750,000 tons. The known reserves are estimated to be 2 million tons of 50 per cent ore, in addition to a very large amount of concentrating ore, with the indications that the potential reserve of high-grade ore is higher than previously estimated.

New Caledonia is the other important source of chromite at present. The total production to the end of 1925 has been 885,000 tons. The reserves, not considering the alluvial chromite or the concentratable rock, are estimated to be more than 1,500,000 tons of 50 per cent ore.

Important deposits exist in Turkish Asia Minor in the province of Brusa. Two mines some 40 kilometers south of Brusa have produced, to 1925, 350,000 tons, and are estimated to contain more than 10 million tons of high-grade ore. The total Turkish reserves are estimated to be about 15 million tons of 50 per cent ore. Other countries and regions that have deposits of chromite but produce little or no ore are: Western and southern Asia Minor; Ural Mountains, Russia; eastern Greece, adjacent islands, and Macedonia; Serbia; Bosnia and Herzogovina; Shetland Islands, Scotland; Norway; Sweden; Silesia, Germany; Portugal; Quebec, Canada; Newfoundland; Atlantic and Pacific Coast states; state of Bahia, Brazil; Guatemala, New South Wales, Australia; New Zealand; Transvaal, and Togoland.

United States.—Investigations of domestic chromite deposits carried on during the War indicate that the United States possesses large reserves of low-grade, high-cost chromite which would be sufficient to meet domestic needs for six or seven years at the present rate of consumption; though a lowering of standard grades and a rise in price would both be necessary to bring about the mining of such reserves. In fact, if the domestic reserves were to be measured by present trade standards as to either tenor or price, the United States would be without chromite. In addition to the ore known, there are certain localities, as in Montana for example where geological indications suggest that other ore-bodies would be proven by further prospecting and development. The available reserves of usable ores credited to this country are estimated at 1,252,600 tons and are in some 2000 scattered deposits in eight states.[15]

Nickel.—The uses of nickel may be divided into four groups, viz., (1) as a component of alloys, (2) as a surface coating for other metals, (3) as a chemical or catalytic reagent, (4) as pure metal.

Of the alloys, nickel steel, as ordinarily termed is the most important. It contains about $3\frac{1}{2}$ per cent of the metal, has great strength and ductility as compared with carbon steel, and is used in various forms in a wide range of industrial operations, and also in the manufacture of armor-plate, ordnance, projectiles, protective deck plate, gun shields, and many other articles of military or naval equipment. The properties of toughness it imparts to steel has rendered the use of nickel for industrial purposes of increasing importance, and this field has widened rapidly. As a structural material, nickel steel has been employed in the construction of the Manhattan and Queensboro bridges in New York City; in the St. Louis municipal bridge over the Mississippi; in the Kansas City viaduct and bridge over the Missouri; in the emergency dam, locks, and spillways in the Panama Canal; and in the reconstruction of the Quebec bridge, St. Lawrence River.

Among other uses of nickel steel, the following may be cited: For locomotive forgings, electric railway gears, marine engine works, stationary engine construction, automobile parts, mill machinery, wire cables, axles, and railway rails, especially in tunnels or on curves.

Monel metal, an invention of the International Nickel Company, and named after the president of that company, contains approximately 67 per cent nickel, 28 per cent copper, and 5 per cent manganese and iron. It possesses great incorrodibility and high tensile strength which has led to its use in many industries. A few of these uses may be mentioned: Propeller blades, valves, castings for oil stills, permanent

[15] International Control of Minerals, 1925.

roofing, tie rods, bolts and nuts, enameling and burning points, dyeing vats, shafting and pump rods.

Cupro-nickel, an alloy of approximately 20 per cent nickel and 80 per cent copper, is used in the manufacture of bullet jackets and other munition purposes. Nickel enters into a great many alloys for electrical use as resistance materials, such as nickel-chromium and nickel-manganese.

The use of nickel in electroplating of metallic objects is widely known, and requires no explanation. A sheet of iron heated in contact with two sheets of nickel can be rolled so as to produce a perfect nickel coating. This material has been used to a certain extent in Germany for the production of kitchen utensils. As a finely divided metal, nickel is used as a carrier of hydrogen in the manufacture of fats and oils, and this property of nickel is largely made use of by soap makers. Nickel oxide is useful for coloring and decolorizing purposes in the manufacture of glass, and there are many chemical uses of nickel and its compounds.

In the pure metallic form nickel is used in the manufacture of sheets which are stamped into watch cases, cigarette cases, cooking utensils, and the like. It is drawn into wire which is often used for spark plugs and electrical leading-in wires.

Nickel Deposits of the World.—While nickel is widely distributed in nature, occurring as an essential constituent of numerous minerals, the known workable deposits of the metal are confined to fewer localities than are those of the more common metals. The deposits of the two countries, the province of Ontario and the French Island colony of New Caledonia control the market for the metal. The proven, or positive, ore of the Sudbury area of Ontario can be conservatively put at 70 million tons, while it is safe to say that the proven together with the probable and possible ore supply exceeds 150 million tons.[16] The metallic content—nickel and copper—probably averages 3 per cent.

While the greater deposits of the Sudbury district in Ontario are measured in terms of millions of tons of ore, those of New Caledonia are reckoned in a few hundred thousands, the greatest of her deposits having contained 600,000 tons; few reach 200,000 tons. A determination of the ore reserves in New Caledonia is not possible owing to their uncertain character, but it might be fair to say that the colony possesses at least as much undeveloped ore of the same grade as she has already mined, in the forty years of her existence as a producer.[17]

Commercial and Political Control of Nickel.—For many years, since 1902 in fact, the production of refined nickel from the vast deposits of

[16] Report of the Royal Ontario Nickel Commission, 1917, p. xxix.
[17] *Ibid.*, p. 251.

nickel-copper ores in the Sudbury district has been divided between two corporations, the International Nickel Company and the Mond Nickel Company, Ltd. The former is a holding company created through the purchase of all or of the majority stock of eight nickel-producing companies in Canada, the United States, and New Caledonia. The company was incorporated under the laws of New Jersey in April, 1902. The refining plant of this company is located at Bayonne, New Jersey, although plans are on foot to establish a refinery at Port Colborne, Ontario. The Mond Nickel Company is the only other company conducting operations on a large scale in Ontario. It is a British corporation organized in 1900. This company possesses several mines and a smelting plant at Coniston, Ontario. The refinery is located at Clydach, Wales. The nickel produced by the Mond process is of exceptional purity, making this nickel favorable for many special uses.

Tungsten.—The large output of machine-made goods in the manufacturing industries depends in no small measure upon the speed and effectiveness of the machine tools which are used in the making of industrial machinery. In the machine, too, the metal tungsten is pivotal. The use of tungsten steel for machine tools permits five times the output of work per man and machine possible with the old-style carbon-steel tool. At least 95 per cent of all the tungsten ores produced go into the manufacture of tungsten powder, ferrotungsten, and tungsten steel for the making of high-speed tool steels. The addition of tungsten to steel gives it the property of holding its temper at a much higher heat than that at which simple carbon steels and most other alloy steels become soft and worthless. This property of red-hardness, as it is called, is very important in cutting tools, as it allows speeding up the work to five or six times the cutting speed allowable with simple carbon-steel tools. The strength and comparative toughness of tungsten-steel lathe tools, even when very hot, permit taking a very heavy cut or shaving off the work, and the chips often leave the tool so hot that they turn blue. The rapid advance in cutting metals and the great increase in efficiency of machine shops in late years is in a very large measure due to the development of tungsten tool steel.

An important use of tungsten ores, though one that consumes only a negligible amount of the metal, is the making of pure tungsten wire for incandescent lamp filaments. For this purpose tungsten metal is combined with about 2 per cent of thorium oxide. A little tungsten goes into electrical contact points for spark coils, etc. For these purposes it is superior to platinum on account of its greater hardness and heat conductivity. The dye industry employs tungsten for fireproofing cloth, and as a mordant for silks the salt has the added feature of serving as a weighting material. In the ceramic industry tungstic oxide is used for producing yellows in glass and porcelain. In the chemical industry tungsten wire and sheet are finding an increasing application as laboratory utensil material, owing to the resistance of this metal to alkali solutions and to most of the acids.

No satisfactory substitute for tungsten has been found for alloying with steel for high-speed cutting tools. Molybdenum has somewhat similar properties, and although it has been used to some extent, especially in Europe, it has never proved so satisfactory and is now used in conjunction with tungsten, replacing only a part of the latter. Molybdenum steel has very desirable qualities, but difficulty is experienced in making a uniform steel alloy with this metal. Stellite, an alloy of cobalt and chromium with tungsten, is sometimes used for cutting tools as a substitute for high-speed steel.

Tungsten Resources.[18]—Tungsten ore is widely distributed and is found in all continents of the world and in a very large number of countries. The bulk of the world's production, however, comes from the Chino-Malayan metallogenic province, which furnishes more than 80 per cent of the world's output. Other important sources are the United States, Bolivia, Argentine, and Peru, while Australia, Italy, Portugal, and Mexico contribute small amounts.

The domestic production comes chiefly from the States of Colorado, California, Nevada, Arizona, and South Dakota. There are several known deposits in Alaska, but their extent and possibilities are unknown. Several potential deposits have been discovered in Washington, New Mexico, Montana, Utah, and Oregon have been producers in the past. The United States draws upon foreign countries for the bulk of its peace time needs. Whether it could meet its requirements from domestic sources in times of emergency is problematical.

Molybdenum owes its importance among the alloying metals of steel mainly in combination with other steel-alloying elements. Thus chrome-molybdenum steels are finding increasing use in structural forms, seamless tubing for aeroplanes, mining equipment, and where resistance to abrasion is an important feature. Experimental work in the development of molybdenum high-speed tool steels is yielding good results and may substitute for vanadium and tungsten to some extent. Molybdenum is also finding useful applications in the electrical and chemical trades.

The world contains innumerable deposits of molybdenum, mostly small, though some of them are extensive and contain large quantities of the metal. Compared with tungsten, for example, there are many

[18] For a detailed discussion of world resources and producing countries see Trade Information Bulletin No. 643, The Marketing of Tungsten Ores and Concentrates.

more occurrences of molybdite (the commercial mineral of molybdenum) and the largest deposits are much larger than those of tungsten. Whenever the world is ready to take molybdenum ores in large quantities at a price that will pay for extraction, the metal will be produced. The United States is favored with an abundance of this mineral and will continue to be an important producer.[19]

Vanadium has gained wide use as an alloying element of steel, and, while it is employed to a small extent in the manufacture of vanadium chemicals, the quantity used thus is altogether insignificant. The principal production of vanadium is in the form of ferrovanadium, used as an alloy in special steels required by the railways, the automobile industry, and in the making of crushers, dredges, air-compressors, large gears, and other heavy-duty machinery in which lightness of design on the one hand, or increased strength on the other must be combined to afford safety and dependability. Vanadium is used in forging steels and spring steels to the extent of 0.15 to 0.25 per cent, while high-speed tool steels require a vanadium content of 0.7 to 2 per cent. These small quantities bring about improvement in the physical properties of the steel altogether out of proportion to the diminutive amount of vanadium present. It is the opinion of men qualified to judge that in the manufacture of carbon tool steel as well as of high-speed tool steel, nothing can replace vanadium. In the railroad field, vanadium steel has at present no alloy-steel competitor. Locomotive forgings are made of carbon-vanadium steel, and its simplicity, ease of working, and excellent physical properties are obtainable without quenching and thus render it unique. In the automotive industry vanadium steels come into competition with nickel steels, nickel-chrome steels, chrome steel, and chrome-molybdenum steel, as well as with plain carbon steel. Vanadium steel seems to have no competitor for quality in the production of automobile springs, and for automobile forgings it affords advantages other than strength, for there are a number of alloy steels which yield essentially the same physical properties, but vanadium steels have superior forging qualities, greater uniformity in response to heat treatment, and better machining qualities than most alloy steels. These characteristics are essential to quantity production while maintaining dependability of quality. For war purposes vanadium steel was used in armor plate, bullet-proof plate, protective deck plate, in gun parts, armor-piercing shells, in airplane engines, and in army trucks.

Vanadium Resources.—The world's known reserves of vanadium are estimated to be sufficient for 30 to 35 years. Beyond that further dis-

[19] Hess, Frank L., Molybdenum Deposits, Bulletin 761, U. S. Geological Survey, 1924.

coveries will have to be made. The most productive ore bodies are found in Peru, Southwest Africa, and North America. The deposits of the Minasregra mine of Peru are controlled by the Vanadium Company of America. These ores are composed of the mineral patronite, a vanadium sulphide, and its oxidized products. No similar known deposits exist either in Peru or in any other portion of the world. This mine first yielded vanadium in 1907 and up to 1923 supplied approximately 75 per cent of the world's output of vanadium. The Minasregra mine lies about 18 miles to the west of Hauraucaca smeltery, near Cerro de Pasco, at an elevation of 16,500 feet. Transportation of the ore, hitherto accomplished by llama trains, at a relatively high cost has been improved by the building of a railroad in 1923, and, as a result, these ore bodies are expected to produce even a larger proportion of the world's output.

Ores of less desirable quality than the patronite deposits of Peru are produced in small quantities in Arizona, Nevada, and New Mexico, also from Spain, Argentine, Mexico, Rhodesia, and more recently, Southwest Africa. These ores have been the source of practically all the vanadium produced abroad but have furnished only a small part of the production in the United States. Thus, the vanadium from imported metallic vanadate ores made up less than 1 per cent of the United States total, up to the end of 1928, and it is believed that domestic ores of the same class have yielded barely as much more, making less than 2 per cent in all. Ores of this class are not known to exist in the United States, except in sporadic deposits, which yield no more than a few tons here and there when prices are high. Recently, there has come to notice a substantial tonnage of vanadinite ore of 5.5 per cent grade in Chihuahua, Mexico, which affords an accessible and promising source of the metal.

CHAPTER XVII

COPPER

COPPER is the paved highway over which man sends his messages, communicates with his distant neighbors, and transmits the power to turn the wheels of industry and transportation. Together, copper and iron, the one because of its high electrical conductivity, the other because of its magnetic properties, enable man to harness electricity cheaply, efficiently and in diverse manners to his service. Fortunately, copper is cheap and abundant. No other metal possessing the properties essential for electrical work can approach copper in quantity or price. Silver is out of the question for electrical work because of the cost, although its conductivity is slightly higher than that of copper. Aluminum is becoming a competitor of copper in the field of electrical transmission, but gives no immediate promise of displacing it generally in electrical machine construction.

Copper, in common with other industrial minerals, has a wide variety of uses. In addition to its function in the electrical industry, the metal is used as an alloying agent with tin, zinc, lead, and antimony in the construction of dwellings and office buildings, in chemical compounds, electrolytes, and in a multitude of manufactured goods. Of all these varied applications, however, the use of copper in the electrical industry is paramount. More than 50 per cent of the metal goes into the several branches of electrical manufacture. Generators, motors, switchboards, lamps, etc., require the greatest quantity. The rapid growth of large generating stations, both steam and hydro, and the increasing mileage of transmission lines is requiring copper tonnages in increasing amounts each year. The expansion of the telegraph and the telephone also demands a large supply of the metal. The electrical industry, with a large expansion still before it, will be the principal user of copper for years to come. Among the electrical industries where copper is used in small but increasing quantities may be mentioned the radio, trolley wire, electrified railroads, locomotives, and electric refrigeration.

As an alloying agent the most important use of copper is in the brass industry, although alloys of tin, nickel, lead, and antimony are finding increasing usefulness. These alloys employ about one-fifth of the copper consumption; brass is the most widely used. It is made into a large number of forms, and as sheet, strip, rod, wire, pipes, tubes, or castings, it enters into practically every important industry. Brass is easily machined, spun, and stamped, and resists corrosion. It is therefore suitable for uses in many places where it is impossible to employ iron or steel. Brass finds a multitude of uses in many lines. It forms boiler and condenser tubes, bearing bushings, in the plumbing trade, in the manufacture of builders' and cabinet hardware and brass bedsteads, in the brass-spinning industries producing cartridges and ornamental articles, and in an extensive line of electrical fixtures.

Bronze is an alloy formed wholly or chiefly of copper and tin in variable proportions, the weight of copper usually exceeding greatly that of tin. This alloy is more fusible than copper and thus better suited for casting; it is also harder and less malleable. The properties of bronze vary widely with the amounts of metals entering into its composition. Statuary bronze consists of about 80 per cent copper and the remainder tin. "Babbitt metal," an anti-friction metal used for bearings, is a form of bronze containing zinc and antimony, besides copper. "Phosphor bronze" is a hard, strong metal used for plungers and pumps which receives its strength from the addition of a trace of phosphorus. By adding a trace of silicon, "silicon bronze," a particularly strong alloy used in telephone wires, is obtained.

The organization of the copper industry is conditioned by the economic characteristics of copper deposits. The major ore bodies of copper are far removed from the world's industrial centers where the metal is consumed. The largest known domestic reserves are in the Rocky Mountain districts of the United States with similar large deposits in difficultly accessible districts in Chile, Peru, Mexico, and Alaska. Recently discovered ore bodies of large proportion are found in the Katanga mineral district in southwestern Congo, Africa, and in Rhodesia immediately to the southwest of Katanga. The smaller deposits of the eastern world are in Spain and Portugal, Japan, Australia, Germany, and Russia.

In addition to remoteness from the population centers, the ores themselves are low in metallic content as compared to the ores of iron or aluminum. Most of the copper to-day is obtained from ores of less than 5 per cent metallic content and the percentage will probably decrease in the future as the richer ore bodies are exhausted and mining technique discovers means of profitably working the lower-grade ores. Moreover, with minor exceptions, copper is found, not in the native state, but chemically combined with other elements in the form of oxides, sulphides, carbonates, or silicates, so that heat reduction is necessary to win the metal from its native state. These characteristics have a definite bearing on the location of copper reduction plants, upon the technique of copper mining and metallurgy, and upon the organization of the industry.

Distribution of Copper Deposits.—The general location of copper deposits has been stated but a more detailed review of the distribution of the important known ore deposits will be undertaken. In proven reserves the Americas vie with Africa in dominating the world. Measured in terms of present production the western hemisphere leads with an output of nearly 80 per cent of the total,[1] and the United States alone supplies more than one-half.

The copper industry of the United States may be said to have begun with the systematic exploitation of the resources of the Keweenaw Peninsula, Michigan. These deposits of native copper were the only important source of the metal until the West opened up competing districts. In fact Michigan produced more copper than any other state in the Union for a period of 40 years from 1847 to 1886. Though large quantities of copper have been taken from these mines—8 billion pounds up to 1926—and a depth of nearly 5000 feet has been reached in some mines, the district shows no signs of immediate exhaustion. The growth in the western states has been so rapid, however, that Michigan now occupies fourth place as a producer.[2]

The second important mining district to come upon the stage of the copper industry is Butte, *Montana*. This also is a deep mine district but, unlike Michigan, the copper is in the form of a sulphide. The deposits are steeply dipping or vertical and it is practically impossible to explore the underground region to determine the extent of ultimate ore reserves.

In 1871 *Arizona* entered the field through the opening of the Clifton-Morenci district. This was followed by discoveries at Bisbee, Jerome, Globe-Miami, and Ajo.

Utah, the last of the four large producers to enter the field, operates important mines at Bingham and Tintic and just across the state line in *Nevada* is located the Ely district.

While these five states produce 90 per cent of the nation's output, copper production is carried on in 14 other states. Important mines that may be mentioned are Santa Rita, New Mexico, Plumas, California, and Ducktown, Tennessee.

The *Alaskan* deposits are found in the Copper River valley where are

[1] Production for years 1920 to 1927.

[2] Butler, B. S., Burbank, W. S., et al., The Copper Deposits of Michigan, Prof. Paper 144, U. S. Geological Survey, 238 pp., 1929.

located the Kennecott (Bonanza) mines, the Beatson mine, and the Mother Lode mine. The Bonanza mine is one of the most remarkable ore bodies ever discovered—a great mass of high-grade ore much of it containing over 60 per cent copper.

The production of copper in *Canada* was not important until about 1881, after which output increased rapidly. Three provinces now contribute to Canada's copper supply—British Columbia, Ontario and Quebec—with a total of 70,000 tons during 1927. Exploration and development is expected to result in a tremendous expansion of production in the course of a few years. The Mining Branch of the Dominion Bureau of Statistics has estimated an output of over 250,000 tons by 1927.[3]

Next to the United States, *Chile* is the most important copper producer in the western hemisphere. "The Chile Copper Company, through its subsidiary, the Chile Exploration Co., is operating the Chuquicamata copper deposit, the largest known in the world, with a maximum length and width of 7500 feet and 2200 feet, respectively, and with an estimated average copper content of 2.12 per cent. The reserves, covering both oxidized and sulphide ores, were 694 million tons at the end of 1919."[4] "The Braden Copper Company, controlled by the Kennecott Copper Corp., owns the Teniento mines, 40 miles from Rancoqua, covering five known ore bodies. The reserves at the end of 1920 were 176 million tons of 2.45 per cent positive copper ore and 88 million tons of 1.87 per cent copper probable ore."[5] "At Chanaral, the Andes Copper Mining Company, an Anaconda subsidiary, owns the Potrerillos mine. The ore body is 900 by 1800 feet in area and has a depth of 850 feet, and at the end of 1919 the total tonnage, developed amounted to 120 million tons of 1.48 per cent copper."[6]

Peru is the second largest producer of copper in South America. A large percentage of Peruvian copper is derived from the Cerro de Pasco property.

Deposits of the Eastern World.—Katanga. Among the foreign districts which promise to become important factors in the copper industry, mention must be made of the Katanga fields, in the heart of the Belgian Congo, and the northern Rhodesian district containing the Bwana M'Kubwa and N'Kana mines. The former is regarded among the largest copper districts of the world. This field lies in the southwestern corner of the Congo and has an area of approximately 650,000 square

[3] Mineral Industry in 1927, p. 145.
[4] Mineral Industry for 1920, p. 169.
[5] Mineral Industry for 1920, p. 170.
[6] Mineral Industry for 1920, p. 170.

miles. It is connected with the South African coast ports by direct railway lines and with Leopoldville and Boma on the west coast by river and railway. An additional railway line from Lobito Bay, Angola, to the Katanga is under construction. The properties are controlled by the Union Miniere du Haut Katanga, whose possessions cover 200 separate deposits over a district 200 miles long and from 30 to 60 miles wide. Since opening the mines in 1908–10, this company has produced well over a billion pounds of copper and has put ten times that amount of 7 per cent ore in sight.[7] This has been obtained from ten of its 200 deposits.[8] "Estimate of ore reserves at the 12 mines of the eastern group is 49 million tons of 6 per cent ore containing 2.8 million tons of copper. The other group is reported to show 20 million tons of 8 per cent copper ore or 1.7 million tons of metal."[9] The total ore reserve proved at the end of 1926 was 77 million tons containing over 5 million metric tons of copper.[10]

Immediately southwest of the Union Miniere properties in northern Rhodesia are copper occurrences which may become the important copper-producers of the British Empire. Development in this section has been rapid since 1925. The ore bodies show many similarities in type to the Katanga deposits. There is little doubt that the potential production of these African companies is great and that in time they will furnish a substantial portion of the world's copper.

Spain and Portugal.—The copper district of southern Spain, which extends into Portugal, has been an important source of the world's copper supply for many centuries, as far back as Phoenician times. It is one of the world's largest deposits, and in spite of the fact that it has been productive for perhaps 3000 years, the present rate of production can be maintained for many years to come. The ore is pyritic and valuable as a source of sulphur as well as copper. Some of the ore is smelted, some is leached of part of its copper content and shipped as sulphur ore, and pyrite containing copper is shipped.

Copper Reserves.—From time to time the fear is expressed that the end of the world's visible supply of copper is in sight and that an ensuing shortage is to be expected. Such predictions of the duration of the world's supply of copper are usually based upon present prices and present mining and metallurgical methods. The question naturally arises: What constitutes a copper ore? The answer to this is determined by the set of conditions which exist under which the extraction of

[7] Mineral Industry, 1926, p. 181.
[8] Sutherland, T. F., Engineering and Mining Journal-Press, August 23, 1926.
[9] Mineral Industry, 1922, p. 185.
[10] Commerce Reports, November 21, 1927, p. 480.

metallic copper from its geologic surroundings and out of its geographical location is profitable. One of the factors in this set of conditions is the demand for the metal. The Katanga deposits in the heart of Africa could not be considered a reserve in 1850 when the demand for copper was relatively small and when the deposits of Michigan could supply practically all that was needed with much lower transportation costs. An increase in demand, reflected in a higher price level, would bring across the line into the body of valuable ore copper deposits hitherto too lean in tenor or too far away from the market. The low price of 1921–22, if continued, would certainly have relegated the high-cost ores of certain of the western mines into the category of non-economic ores. The uncovering of large deposits of rich ore in other localities would have the same effect and, even now, the fear is expressed that the Chilean and African ores will have this effect on domestic deposits. These conditions may be considered temporary, however, for a high-grade mine, however large, is eventually exhaustible and, sooner or later, the leaner or higher cost mines will be called upon to meet the demand.

Another factor of greater importance, however, in its influence upon the size of the reserve is the effectiveness of recovering metal from the earth. This factor is in itself composed of many elements. First may be mentioned the scale of mining operations. When capital is available in abundant quantities, the character of mining operations is vastly different from the methods of a small operator working with limited capital and crude equipment. Under the former condition systematic exploration through geologic examination of the territory, core drilling, the use of power drills, and high-power explosives is possible and uncovers large ore bodies at a relatively low cost.[11] Capital equipment of large dimensions such as steam shovels in open-pit mining, or shafts and tunnels equipped with an elaborate haulage and lifting system can be employed. All of these are unavailable to a small operator and, as a consequence, scale of operations alone has created economic ore bodies of vast extent both in this and foreign countries.

Of equal significance are the advances in the art of ore dressing. These will only be mentioned at this point together with their chief contributions. The manner in which they effect their contribution will be discussed later.

Finer grinding of ore has served to steadily increase the percentage of copper-bearing minerals separated from the useless gangue.

The introduction of flotation, preceded by the pulverization of the ore into an impalpable powder, has resulted in recovering part of the

[11] Strauss, S. D., What Kept Copper Prices Down, Eng. Min. Jour., Vol. 127, No. 20, May 18, 1929, pp. 798–801.

minerals hitherto lost when the grinding was not so fine: it also effects a more complete separation of minerals from gangue. When milling and water separation alone were practiced the unavoidable waste was greater.

Selective flotation, the separation of several minerals from each other as well as from the gangue has added to the reserve by creating economic ores out of complex mineral deposits.

The development of the leaching process has added carbonate, oxidized, and silicate ores of copper to the available reserve as well as rendering the reworking of mine tailings profitable. The introduction of flotation necessitated the development of the reverberatory furnace, the combination of which is more economical in ore dressing and reduction than the coarse grinding and reduction in the blast furnace. No reason exists for believing that the final word has been said in the technology of copper recovery. Improvements in mining, milling, reduction, and mine management are constantly being made, all of which tend to reduce costs and push farther down the lower limit of copper percentages in ore that can be recovered and each improvement has its effect on enlarging the body of the reserve.

In Table XI are given some figures on proven reserves of several

TABLE XI *

Ore Reserves of Various Copper Companies

	Date	Tons	Copper Content, Per Cent
Andes	December, 1924	137,400,000	1.51
Braden	" 1927	244,000,000	2.19
Calumet and Arizona	" 1925	1,829,546	4.15
Calumet and Hecla	" 1925	108,143,000	1.2
Chile Copper	" 1922	684,259,912	2.12
Consolidated Coppermines	August, 1926	20,729,135	1.55
Engels	December, 1925	2,437,608	2.00
Granby	" 1925	8,896,320	1.77
Howe Sound	" 1925	5,643,712	2.10
Inspiration	February, 1926	96,010,935	1.40
Katanga	December, 1926	85,054,000	6.89
Miami	" 1927	106,609,000	0.94
Nevada Consolidated	" 1927	277,483,000	1.51
New Cornelia	" 1927	57,860,351	1.40
Noranda	January, 1926	944,525	6.7
Ohio	December, 1923	36,000,000	0.3
United Verde Extension	" 1927	960,000	8.00
Utah	" 1927	572,000,000	1.10

* Mineral Industry in 1927, p. 128.

domestic and foreign mines. They are not to be regarded as a definite statement of the copper reserves of the world, for not all the known mines are included, but simply to convey an approximate idea of what is "on hand" by the larger copper companies. No justification exists for a statement purporting to give a definite figure of world copper resources. The crust of the earth has not been explored thoroughly in two dimensions, let alone three, and there is no reason to believe that ores will not be uncovered in the future whose existence at the present time is unsuspected. Doubtless the main ore bodies of such thoroughly prospected areas as the United States and Europe are known, but there is yet much unprospected territory in Africa, Australia, and South America. A statement of reserves then is not to be made on the basis of the metal physically present in the earth's crust but rather upon the set of conditions, economic and technical, under which the metal is being mined.

THE RECOVERY OF COPPER FROM THE ORE

Description of Copper Ores.—Copper ores are characterized by a low content of metal when they are compared with other important metals such as iron, aluminum, or lead. The porphyry ores, the most important of the domestic ore bodies, average about 1½ per cent.[12] Ores of similar origin and characteristics in Chile average slightly over 2 per cent. Those of Katanga are reputed to run as high as 7 and 8 per cent. Other and smaller ore bodies in this country and Alaska are even higher, but their contribution to the total copper supply is relatively small. Although copper sometimes occurs in its native state, as in Michigan, most of the metal is combined with other elements to form sulphides, oxides, carbonates, or silicates; of these the sulphides are most abundant. Most copper ores contain variable amounts of other metals, among which are lead, zinc, gold, silver, and in some deposits platinum, palladium, and other rare metals.

The deposits of this country fall into four classes, (1) the porphyries, mainly surface ores, (2) the deep deposits of Montana and Michigan, (3) small bodies of rich ore, and (4) scattered small deposits.

The so-called porphyry type of copper mines constitute the largest known domestic reserves. These are horizontal deposits lying close to the surface and aggregating over 700 million tons of 1.44 per cent copper ore. The copper minerals are disseminated through large masses of rock and also form small veins and aggregates of veinlets. Usually

[12] Cameron, R. H., The Copper Industry, Senate Document 153, 69th Cong., 1st Session, 1926, p. 6.

they are so thoroughly and uniformly distributed through the rock that it is all low-grade ore. This type of deposit is worked by either open cuts or pits in a manner similar to that employed in the Superior iron mines or by extensive underground systems. They are owned for the most part by Utah, Chino, Ray, Inspiration, Nevada Consolidated, and New Cornelia companies.

The ore bodies of the Nevada Consolidated, Utah, and Chino are so near to the surface that it is only necessary to strip off the overburden with steam shovels and mine the ore by the same method. In the case of Miami, Inspiration, and Ray, and part of the Nevada Consolidated, underground or so-called caving methods of mining are employed.

The deep mines are represented by two districts—Butte, Montana, and Keweenaw Peninsula, Michigan. These are the oldest producing districts in the United States. Butte mines extract ore from steeply dipping veins to a depth of 3400 feet. The veins generally range in thickness from a few inches to many feet, but some of them expand in places to form lenses or irregular bodies of great width, and some extend to depths of thousands of feet. Associated with the copper ores in the Butte district are also zinc and manganese deposits.

The deposits of northern Michigan are on the Keweenaw Peninsula projecting into middle Lake Superior. Copper has been mined there on an important scale for over 50 years and several mines have reached a vertical depth of over 5000 feet. Michigan produced more copper than any other state in the Union for a period of 40 years from 1847 to 1886. It is now exceeded by Arizona and Montana, and closely followed by Utah.

Certain richer, usually massive but irregular, deposits, which are located for the most part in Arizona, constitute the third important general class. These deposits produce one-fourth of the total domestic output. Bisbee, Jerome, and Globe, Ariz., and Kennecott, Alaska, are the main localities. Owing to the irregular nature of the deposits and the distance from the surface at which the ore is found, large reserves cannot be blocked out in advance and, hence, the ultimate reserve is undetermined. In addition to these there are many smaller deposits of which the most distinct class are the pyritic bodies, notably those of California and Tennessee. Such deposits are often profitable even when of low grade because the sulphur as well as the copper is recovered.

The production of metallic copper from the ore requires at least three distinct operations—mining, smelting, and refining. Each of these operations embraces several processes of which the preparation of the ore for smelting is ordinarily the most varied and complicated. The low metallic content of copper ore obviously necessitates its concentration and smelting near the mines. A brief description of the major steps in the reduction of copper will help to explain the features that characterize the copper industry from mine to the consuming centers. Recovery of the ore is accomplished either by open-pit mining as in many of the shallow, blanket-like porphyry deposits or by shafts and tunnel mining as in the case of deep deposits.

As the ore is received from the mines it is crushed to 2-inch sizes and smaller to release the enclosed valuable minerals. The remaining material, termed "middling," still contains small particles of valuable minerals, hence this is subjected to further grinding and separation by means of water jigs. The product of the second grinding is again divided into "Concentrate" and "middling" and the latter is treated to grinding and separation. The Middling resulting from this last step is ground to an impalpable powder from which the remaining valuable minerals are recovered by "flotation."

Flotation may be aptly called an up-side-down process; the heavier minerals are made to rise in a mass of water while the lighter minerals sink. This is brought about by taking advantage of the fact that, when certain oils are mixed with the ore, they stick to the metal-bearing minerals but do not attach themselves to the barren minerals. This selective action is aided by the use of small quantities of sulphuric acid and bubbles of air driven through the mixture.

Although the principle of flotation is not yet thoroughly understood the modus operandi can easily be shown by a simple experiment.

If a glass container be nearly filled with water and a small amount of oil added to it, the oil will form a thin layer or film on the surface of the water. If, then, a mixture of the finely pulverized sulphide ore of copper and water be added, with constant stirring, to the oil and water in the glass, it will be found that the particles rich in copper will become entrapped by the oil and will rise to the surface, while the barren material (gangue) will sink to the bottom of the tumbler. This frothy layer of oil and copper may than be removed and the oil driven off by heat after which the copper sulphide remains practically freed of waste material.

With present practices 95 per cent of the copper is recovered from the ore, whereas previous to the introduction of flotation recovery was low, for two reasons: Earlier practice did not carry the fine grinding far enough to release all of the copper-bearing mineral, some of the tailing going to the dump in sizes as coarse as a sixteenth of an inch, which is three times the diameter of the coarsest particle now sent to waste; and the methods then used in concentrating the very fine sizes were much less efficient than flotation.

The flotation process is followed by roasting and bessemerizing for the purpose of preparing the copper for the final refining process. The first step burns out the sulphur and the second reduces the copper to an impure metallic state. From its appearance the metal so produced is called "blister copper"; it contains about 99 per cent metal.

Leaching.—Previous to adopting the flotation process of concentration, the loss of copper in the tailing averaged thirteen pounds in some instances. This copper waste, originally a sulphide mineral, was converted in the waste heap to a carbonate through the action of lime water and weathering. In this form the copper is easily dissolved by sulphuric acid. The precipitate obtained from the leachings is smelted down for its copper content. The development of the leaching process not only recovers hitherto waste copper in the mine tailings but also is applicable to certain types of oxidized ores. If flotation made possible vastly increased supplies from the porphyry areas in the United States, leaching has opened up a new field of production in the low-grade, oxidized deposits of Chile and Africa. The African fields promise to apply both methods.

Refining the Smelted Copper.—The final process through which the major portion of the copper of commerce passes is that of "electrolytic" refining. In the previous operations which end with furnace refining, gold, silver, and small amounts of base metals are still retained in the copper, and the twofold object of this further step is first, the recovery of the precious metals in salable form, and secondly, the removal of the base impurities which adversely affect the conductivity of the metal required for electrical purposes. In only one producing district of the United States do we find large amounts of copper so pure as to require no electrolytic refining. This is in the Lake native copper district. Some copper is produced from the smelting furnaces which is low in precious metals and sufficiently free from impurities for certain low-grade uses without electrolytic refining. This copper is usually unfit for uses requiring a high-grade material, such as electrical transmission, brass manufacture, and rolling, but is suitable for copper castings, and a large part of it is put to that use.

From the nature of the process of copper reduction, it may be inferred that smelting operations will be carried on as near the mines as possible in order to effect the greatest possible reduction in bulk before transportation to the market.

Hitherto, refineries have been located near the centers of population and industry. As a result, the Atlantic Seaboard had a virtual monopoly on the business of copper refining. Abroad the practice was prevalent to an even greater extent. Belgium and Germany, for example, are important metallurgical centers but unimportant metal-mining countries. Lately, however, the tendency has been to construct refineries near the source of supply. Several refineries have been built near El Paso, Sudbury, and Manitoba. The tendency to build at the ore and power supply rather than near the market has resulted from the widespread development of power, rapid transportation, and lower construction costs.

The Position of the United States in the Copper Industry.—Copper is the one important industrial metal in which the United States dominates the world, both in production and consumption. This country has also been responsible for financing and developing more successful copper mines abroad than any other country. This has been facilitated by the presence in the Western hemisphere of the world's chief copper deposits and also by the advances in copper mining, milling, and metallurgy which have been in great measure the work of United States engineers. England and Japan control some copper, but it is small as compared with the amount controlled by the United States.

The dominant position of copper among the non-ferrous metals necessitates a world survey of the producing and consuming centers and the relative position of the United States in each among the nations of the world. The world's production of copper since 1919 has averaged slightly over a million metric tons a year, falling as low as 480,000 tons in 1921 and rising to 1,600,000 tons in 1928. The trend has been steadily upward. Of this the United States has produced more than 50 per cent, Chile more than 12 per cent, and more than 25 per cent by Africa, Canada, Japan, Mexico, Peru, Spain, and Portugal. These nine countries account for more than 90 per cent of the world's production in the recent period, 1919 to 1926, inclusive.

The copper consuming areas of the world are concentrated around the shores of the North Atlantic, in the industrial districts of the world. Half of the world's copper moves to the Atlantic Seaboard at Baltimore, Md., Perth Amboy and Carteret, N. J., and Laurel Hill, N. Y. The combined capacity of these copper refineries is 2 billion pounds of copper annually. Three other refineries in the United States, located at Great Falls, Mont., Tacoma, Wash., and Hubbell, Mich., have an annual refining capacity of 280 million pounds.[13] Several other refineries are projected or in building near the ore supply.[14]

The Nangatuck Valley in Connecticut is the center of the brass industry, and most of the wire drawing is done close to New York City and Kenosha, Wis.

[13] Spurr, J. E., and Wormser, F. E., The Marketing of Metals and Minerals, 1925, p. 46.

[14] Eng. Min. Jour., Vol. 127, No. 20, 1929.

The foreign consumers of copper are located principally in northwestern Europe, which uses three-fifths of the continent's consumption; in the Orient Japan is the dominant user.

Four countries, the United States, Great Britain, Germany, and France used more than 80 per cent of the world's copper in the past decade. Naturally the major part of the metal is consumed in industrialized countries with relatively high standards of living. Industrial expansion in Asia, Russia, and Africa, while moving forward, is slow, and provides only a small outlet for copper. Electrification and modern means of transportation and communication must come about before large copper markets can be developed.

With this brief survey of world mines and markets, we can make a more detailed study of the position of the United States.

The dominant position of this country is due to its combined commercial control over reserves, foreign as well as domestic, its preeminent position in the smelting and refining industry of the copper world, and its control over the markets for finished copper goods.

American control of the copper industry through mine ownership is confined largely to the Americas. The largest producer outside of the United States is Chile. Three mines from which comes 90 per cent of the Chilean copper are owned or controlled by the Anaconda Copper Company and the Kennecott copper group. In Peru, the Cerro de Pasco mine, the principal producer, is owned in the United States, and the Cerro Verde mine at Arequipa is owned by a subsidiary of Anaconda. In Mexico, the Nacozari mine of the Moctezuma Copper Company, one of the important producers of Mexico, is controlled by the Phelps Dodge Corporation. Numerous other mines of smaller capacity and reserves are divided among American, French, and British ownership but, compared with the large American-owned mines, they are negligible factors in the copper industry of the western world.

The second factor through which the copper industry is controlled is through the ownership of smelters and refineries, particularly the latter. Practically all of the domestic blister copper as well as important amounts from the rest of the Americas and Africa go to the refineries in the United States. The refineries practically control the movement of copper since a copper producer must obtain electrolytic refining in order to market his product. The combined effect of mine and refinery control by domestic capital results in a marked movement of copper into the country and an outflow of refined copper goods.

The American Copper Companies.—The remarkable degree of control of the copper industry by the United States is due in no small part to the corporate organizations engaged in the mining, smelting, and refining of copper and the manufacture of copper goods. The successive steps in the improvement of the technology which changed copper mining from a primitive to a highly developed, large-scale, mechanized industry was accompanied by an evolution in corporate organization. The copper corporations have expanded both horizontally and vertically. Their operations, both in mining and reduction, have extended beyond the national borders, and have become world wide in their extent. The dominant groups in the copper world are: Anaconda Copper Mining Comapny; the Kennecott group; the American Smelting and Refining Company; the Phelps Dodge Corporation; and Calumet and Hecla.

The Anaconda Company has a broad charter, permitting it to acquire, mortgage, lease, assign, and transfer the capital stock, bonds, or securities of any other corporation. This company and its subsidiaries engage in mining, smelting and refining copper, and in the manufacture of copper wire, brass, and brass goods. Anaconda is the largest though not the controlling interest in the copper industry. It controls the large Chilean deposits—outranked only by Katanga—and own the largest consumer of copper metal, the American Brass Company. Associated with it is the International Smelting Company (wholly owned). Its Montana properties include 36 mines, copper and zinc smelting plants at Great Falls, a copper refinery and a wire and rod mill; it controls the Walker Mining Company of California. In South America the Anaconda Company controls copper deposits of Chuguicamata, the largest known in the world, through the Chile Copper Company, the Andes Copper Mining Company, controlling the Potrerillas mine, and the Santiago Mining Company. In 1926 it gained control of Giesche Spolka Akcyjna, which owns deposits of zinc ore and coal in Silesia. Through the International Smelting Company it owns copper smelters at Miami, Ariz., and Tooele, Utah, and the International Lead Refining Company in East Chicago. The American Brass Company, also a subsidiary of Anaconda, is the outgrowth of seven subsidiary brass companies. This company has plants located in six cities in the United States and Canada employing 12,000 men. It has been engaged in the manufacture of copper and brass products over sixty years. The purchase of the American Brass Company has resulted in a completely integrated organization covering every branch of the industry from mining of the ore to selling of the finished product. In addition to its Montana plant, Anaconda also owns a refinery at Raritan, N. J.

The Kennecott Copper Group.—"The most important purely copper-producing horizontal combination is that of Anaconda's principal rival, the so-called Kennecott group. The mines in this group have, even since they became important producers, all been under at least affiliated control, represented by the Guggenheim-Hayden-Stone interests. The principal units of the group are the Kennecott Copper Corporation and the Mother Lode Coalition Mines Company of Alaska, the Utah Copper Company of Utah, the Nevada Consolidated Copper Company of Nevada, the Ray and Chino mines of Arizona and New Mexico, respectively, and the Braden Copper Company of Chile."[15]

The American Smelting and Refining Company does not confine its activities to copper alone, but is engaged in the marketing and refining of a large number of non-ferrous metals. It owns 25 smelting and refining plants, 18 in the United States distributed over 12 states, 5 in Mexico, and 2 in South America. It owns and operates 11 metal mines, all in Mexico, and 5 coal mines, and operates 5 metal mines which are controlled by it. It mines gold, silver, copper, lead and zinc ores, and coal. It smelts its own ores of all these metals, and also most of the ore produced by the lesser mines of America. It refines not only these five metals, but manufactures them into copper sheets, rods, tubes, zinc white and zinc dust; sulphuric acid at Perth Amboy, N. J., and Garfield, Utah. It refines and sells bismuth, cadmium, arsenic, nickel, platinum, palladium, and selenium largely from the slimes of its electrolytic refineries. Control of the American Smelting and Refining Company rests with the Guggenheim interests.

Calumet and Hecla is a consolidation of five Michigan mining companies. It owns an uninterrupted stretch of eleven miles along the three lodes of the Lake Superior copper belt. More than 160,000 acres are included in this property which covers about a quarter of the entire peninsula north of the Portage Lake waterway. The holdings of this company represent about 40 per cent of the value of copper properties in Michigan.

Two refineries, the Nichols Copper Company at Laurel Hill, Long Island, and the American Metal Company, are independent of mining companies.

The Marketing of Copper.—Copper is in some respects unique as a market commodity. The electrolytically refined metal is a standard product, hence there are no market quotations on "grades" of copper. Moreover, producers and consumers are relatively few in number, the metal being sold direct rather than through a copper exchange. While the technique of copper production, from mining to electrolytic refining, is carried on efficiently, the marketing of copper has not been satisfactorily handled from the standpoint of the producers.

[15] Richter, F. E., The Copper Industry in Representative Industries in the United States, edited by H. T. Warshow, 1928, p. 239.

The price of copper, under normal conditions, is governed generally by the law of supply and demand under conditions of free competition. Normally the price of copper would coincide roughly with the cost of production of the "marginal supply," that is to say, the most expensively produced metal that is needed to meet demand. The smaller the proportion that high-cost production bears to the total, the less likely is the price to remain at high levels. This brings us to a consideration of the unit cost of production of copper. In this connection A. B. Parsons states that "considerably more than 95 per cent of the current supply is produced at a cost, exclusive of depletion, of 14 cents or under. It is highly improbable that one-half of 1 per cent of the total costs 17 cents. Theoretically, a situation such as this corrects itself automatically:[16] The high price stimulates increased production, the supply outstrips demand, and the competition among sellers to dispose of their product forces the price to recede. As the price goes down those who are unable to produce at a profit normally stop producing. The progressive withdrawal of high-cost producers as contributors to the supply causes an equilibrium to be reached between supply, demand, and price. A few producers who can just break even continue to turn out metal because it is expensive to shut down mines and they have hope that an increase in consumption and demand presently will raise the price so that they can again operate at a profit. In theory, it is the production cost of these so-called marginal producers that establishes the price. If, on the other hand, consumption has a decided upward trend, production may lag behind and the bidding of buyers against each other raises the price. As the price goes up, the progression is reversed, and more and more of the higher-cost producers become contributors to the supply. When enough of these have begun to operate, equilibrium is again established and the price is fixed approximately at their cost of production. Naturally, in practice this fundamental economic law does not operate with perfect precision and promptness. For example, if consumption (or apparent consumption) increases with great rapidity, and if for any reason production cannot be or is not increased rapidly, a situation may be created where for the time being sellers can obtain almost any price. This apparently is what has happened in the copper industry early in 1929.[17]

The customary behavior of the copper market has been a phenomenon of "buying waves" with intervening dull periods. It was these inter-

[16] Refers to the temporary high prices exceeding 20 cents that prevailed early in 1929.

[17] Parsons, A. B., What Will Copper Do? Eng. Min. Jour., Vol. 127, No. 14, April 6, 1929, pp. 554–559.

vening periods of dullness that were unsatisfactory to the sellers of copper. The buyers knew that the industry was capable of producing to about 20 per cent in excess of normal consumption, hence there was little likelihood of a long-continued period of high prices. Hence by staying out of the market until one of the primary producers lost his nerve and cut prices, the result would be a general reduction. The ensuing low prices resulted in increased buying until a fair price level was again built up only to be broken in the same way.

The first step in establishing a firmer and more stable price was the formation, in October, 1926, of the Copper Exporters, Inc.,[18] an association of American and European producers controlling 90 per cent of copper production. This organization fixed the price of copper sold to the European consumers. Sales were made directly to the consumers and the speculative dealer in copper was eliminated. The copper Exporters, Inc., was followed by the organization, on November, 1927, of the Copper Institute, the membership of which is substantially the same as the American members of the exporting organization.

The purpose as set forth broadly in the constitution is "to aid the copper industry through wider knowledge and clearer understanding of the economic factors affecting the production, manufacture, distribution, and consumption of copper and copper products." The principal activity thus far has been the collection, compilation, and distribution among its members only of very complete and informing statistics concerning production, prices, sales, and deliveries of copper. The immediate effect has been a marked change in price behavior to the advantage of the sellers. Prior to the organization of the Institute, some seller, in a period of meager sales, would lose his nerve and precipitate a general decline in the market by shading his price. Under the Institute regime each seller is given an accurate statistical picture of the market position as a whole. He is then able to gauge the probable demand on the part of the consumers and shape his selling policy intelligently. The mining companies also, with this information on hand, can guide their production policies so as to prevent an undue accumulation of copper stocks.[19]

[18] Organized under the provisions of the Webb Act.

[19] See the Mineral Industry in 1927, pp. 117–124, for a description of the activities of the Copper Institute and a copy of the constitution.

CHAPTER XVIII

BAUXITE AND ALUMINUM

THE distinctive characteristics of the metal aluminum are its lightness, high electrical conductivity, resistance to corrosion, and the strength of its alloys. These properties, singly or combined, insure for aluminum a place of ever-increasing importance in the service of man. Beginning with a domestic output of 83 pounds in 1883 the world production of aluminum is well over 200,000 tons.[1] The key to the value of the metal is its lightness. Volume for volume it has about one-third the weight of steel. It is this extraordinary low specific gravity which is causing the makers of automobiles and railway equipment to regard this metal with increasing favor. Hence the transportation industry has made use of aluminum in everything from bicycles to railway trains. The advantage lies not only in decreased motive power required but also in reduced impact on track or highway as well as greater speeds. The automobile industry in 1927 used 65 million pounds of aluminum, nearly one-third of the entire output of the metal. The use of aluminum in body construction is limited to the higher-priced cars due to the high cost of the metal. In piston construction, the advantage is not only that of lightness but also greatly increased heat conductivity. "This advantage is apparently sufficient to warrant increased compression ratios in motors without other structural change than the substitution of aluminum-alloy pistons. For body construction of automobiles and buses large savings in weight are possible."[2]

Aluminum has also been used extensively in railway cars by the Illinois Central Railroad in its suburban-type cars with considerable saving in cost of power as well as in track and road-bed wear.[3] The Cleveland street railway system is operating an all-aluminum street car with a saving of 25 per cent in power consumption.[4] In aircraft construction numerous American and European applications of aluminum

[1] Mineral Industry, 1927, p. 15.
[2] Mineral Industry, 1926, p. 43.
[3] Mineral Industry, 1926, p. 43.
[4] Electric Railway Journal, April 9, 1927.

alloys have been made in such parts of the motor and wing and fusilage cover. Notable advantages have been obtained with light-metal propeller construction also. Reports indicate that certain of the European countries are abandoning wood for aircraft use and are gradually going to all-metal airplanes as their standard for military and naval uses.

The combined properties of lightness and good conductivity have made of aluminum a serious competitor of copper in the construction of long-distance transmission lines. Weight for weight, aluminum has twice the conductivity of copper. Hence when aluminum is sold at less than twice the price of copper per pound it affords economy in both construction and maintenance. Its lighter weight permits material economy in construction and number of supporting towers. An aluminum conductor of given electrical capacity has greater surface and consequently lower corona loss than a similar copper conductor. More than 200,000 miles of such conductor have been sold by one manufacturer alone.[5]

Other Uses of Aluminum.—While the transportation industry, particularly automobiles, is the largest consumer of aluminum, considerable quantities are also absorbed by the radio industry, the manufacturers of metal furniture, cooking utensils, aluminum paint, and as a deoxidizing agent in steel manufacture. Aluminum plating is now said to be successfully accomplished.

Aluminum Alloys.—While aluminum has a distinct field of usefulness in the form of a substantially pure metal, it is in the field of light alloys that the greatest progress has been made. Duralumin, sometimes called "duraluminum," is the most popularly used of the various aluminum alloys so far developed. Simple duralumin has a composition of about 4 per cent copper, less than 1 per cent each of magnesium and manganese and the remainder aluminum. The remarkable feature of this alloy is that it can be hardened materially by quenching from suitable temperature with the hardening increasing markedly during the period of aging. It can be rolled into sheets or forged and easily cast. It has the strength of cold rolled steel, yet is only one-third as heavy.

Recently a process of electrolytic refining and purification of aluminum has been made commercially available.[6] The use of this pure aluminum permits the manufacture of certain heat-treated cast copper-aluminum alloys hitherto not available. Some of these have a tensile strength as high as 50,000 pounds per square inch while corre-

[5] Mineral Industry, 1926, p. 44.

[6] Industrial and Engineering Chemistry, Vol. 18, p. 922, September, 1926.

sponding alloys made from lower-grade aluminum give at best only one-half this strength.[7]

Occurrence of Aluminum.—Aluminum is the most abundant of metals. It is an essential constituent of nearly all important rocks except peridotites, sandstones, and limestones, and even in these its compounds are common impurities. It does not occur in nature in the native state; it is found chiefly in feldspars, micas, clays, etc., and in a more concentrated form in bauxite and cyrolite. The average content of aluminum in the earth's crust is about 8 per cent.[8] The most important ore of aluminum is *bauxite*. The crude ore of commercial grade contains at least 52 per cent of aluminum, although material is mined of varying content ranging from 40 per cent to 70 per cent.[9] The principal bauxite deposits of the world are in the provinces of Var and Hérault, southern France, in Jugoslavia, in Dalmatia and Istria;[10] in the southern part of the United States—Arkansas, Georgia, and Alabama;[11] in British and Dutch Guiana; in northwestern Ireland. Minor deposits are located in Germany, Russia, Venezuela, French Guiana, Brazil, Africa,[12] Australia, India,[13] and probably China. It is believed that the tropical countries contain immense reserves.

Active Ore Deposits.—Although a dozen or more countries produce bauxite ore, six of these account for the major portion, 90 per cent or more. These countries are France, the United States, Italy, British Guiana, Dutch Guiana, and Jugoslavia. An examination of production over a period of years, 1921 to 1927, shows some interesting trends. France leads in output and is increasing each year. British and Dutch Guiana and Jugoslavia are increasing at rapid rates, while the United States is showing a decline. The explanation of these production movements lies in the character of the ore, its geographical location, its political control, and the technology of the industry. The Dalmatian (Jugoslavia) and the Guianan deposits are the major sources of supply for the American and Canadian aluminum plants and, as such, are replacing the domestic sources.

[7] Mineral Industry, 1926, p. 40.

[8] Clarke, F. W., The Data of Geochemistry, Bulletin 770, U. S. Geological Survey, p. 36.

[9] Hill, J. M., U. S. Geol. Survey Mineral Resources, 1916, Pt. 1, pp. 162–163.

[10] Gordon-Smith, G., Bauxite Deposits in Jugoslavia, Comm. & Financial Chronicle, Vol. 125, Sept. 10, 1927, pp. 1383–1384.

[11] Morse, P. F., The Bauxite Deposits of Mississippi, Bull. 19, Miss. State Geological Survey, December, 1923, 208 pp.

[12] Emory, Lloyd T., Bauxite on the Gold Coast, Eng. Min. Jour., March 13, 1926, Vol. 121, No. 11, pp. 443–446.

[13] Fox, C. S., Bauxite, 1927, xii, + 312 pp.

The Commercial Ores of the United States.—The bauxite deposits of the United States are in Arkansas, near Little Rock; in central Georgia; in the adjacent parts of Georgia, Alabama, and Tennessee; in northeastern Tennessee; and in northeastern Mississippi. A deposit of bauxitic laterite and bauxite is reported in Riverside County, California.[14]

Arkansas contains the most important bauxite deposits in the United States. Since 1910 that state has produced more than 80 per cent of the bauxite mined in this country. Nearly all of it is used in the manufacture of the metal aluminum. The bed occurs near the railway in the vicinity of Little Rock, Pulaski County, and near Benton, Saline County. The exposures vary in size from an acre to twenty acres or more, and aggregate over a square mile.[15]

The noted deposits of bauxite in Alabama and Georgia are those of the Coosa Valley in the northwestern part of the state. These deposits extend as an irregular belt between Adairsville, Ga., and Rock Run, Ala., a distance of approximately 120 miles.

Bauxite deposits were discovered in Tennessee near Chattanooga during 1906. Three groups of deposits are now known, two near Chattanooga, in Hamilton County, and a deposit near Keensburg, Carter County, in the northeastern part of the State. As in the Georgia-Alabama fields, the ore forms large, irregular deposits in residual material.

Mississippi.—Considerable deposits of bauxite occur in northeastern Mississippi but they are of rather low grade and unsuitable as an ore for aluminum, and refractory and chemical products of bauxite. Drying and washing may aid in concentrating some of these ores to a commercial grade. The use of these low-grade ores in the manufacture of quick-setting cements offers a possibility.

Uses of Bauxite.—The chief uses of bauxite are (1) in the production of metallic aluminum, (2) in the manufacture of aluminum salts, (3) in the manufacture of abrasives, and (4) in the making of refractories. Most of the ore produced is used in the manufacture of aluminum. The principal commercial salts of aluminum are aluminum hydroxide, sulphate, alum, the chloride, and acetate. Aluminum hydroxide is used principally in the manufacture of other aluminum compounds; also in the preparation of lake colors, in waterproofing fabrics, cement making, and in medicine. No figures are available to show the quantity produced. Colloidal aluminum hydrox-

[14] Morse, P. F., The Bauxite Deposits of Mississippi, Bull. 19, Miss. State Geol. Survey, December, 1923, p. 51.

[15] Brauner, J, C., Bauxite in Arkansas, Amer. Geologist, March, 1891, Vol. 12, pp. 181–183.

ide is used in sugar refining. Aluminum sulphate is used in paper making for the preparation of fixing material, as a mordant for dyeing, for the purification of water, for tanning skins, and for the refining of mineral oils, and for other uses where crude alum was formerly employed. Aluminum chloride is used in the refining of mineral oils, for carbonizing wool, and in the manufacture of certain organic compounds. Aluminum acetate is used as a mordant in calico printing, and dyeing; for the manufacture of lake colors, and in the waterproofing and fireproofing of fabrics.

Bauxite abrasives are made by fusing bauxite with carbon in the electric furnace, breaking down the fused product, pulverizing, and sizing the grains. If made from pure bauxite the product is practically an artificial corundum. The manufacture of aluminum abrasives to silicon carbide abrasives in this country is about in the ratio of ten to one. Varying degrees of hardness and toughness in the abrasive may be obtained by using different grades of bauxite.

High-alumina refractories contain from 50 per cent to 75 per cent alumina. They are made chiefly from bauxitic clay and diaspore earth, although a small amount of bauxite is used annually. Bauxite bricks are made by mixing calcined bauxite or high-alumina clay with a bonding material such as fireclay, sodium silicate, or lime, shaping by hand or machine, and burying in various types of brick kilns at a high temperature. Another type of aluminous refractories is made by fusing bauxite in an electric furnace and casting the molten material in molds. The demand for this type of refractory is growing because of the ever-growing need for better refractories. Pure bauxite melts at about 1820° C., and pure alumina at about 2050° C., but the lower grades of bauxite brick melt at 1740° C. or less. The value of bauxite refractories depends upon their chemical inertness at high temperatures.

Aluminum Manufacture, Technology of.—In addition to the bauxite from which the metal is extracted, the raw materials required in the manufacture of aluminum are cryolite or fluorspar, coke, and electric power. Broadly speaking the operations may be said to consist of two steps, (1) refining of the crude bauxite to produce alumina—a white substance of substantially pure aluminum oxide—and (2) the electrolytic reduction of alumina to the metal aluminum.

The first step, the refining of crude bauxite, is necessary to rid the ore of the impurities which interfere with the successful electrolytic reduction of the oxide to metal. Crude bauxite as it is obtained from the mines contains silica, iron oxide, titanium oxide in small amounts, water, and clay. The removal of these impurities, called "calcining," is now accomplished by the Bayer process.

One refining plant for bauxite, until 1928, the only one, is located at East St. Louis, Ill. The Aluminum Company of Canada, Ltd., has completed a plant at Arvida, Quebec, and crude bauxite is now shipped directly to the Arvida plant for calcining instead of going to East St. Louis as heretofore.

The refined product of the calcining plant, alumina, is an intermediate product in the final preparation of aluminum. This step brings into use the raw materials, cryolite or fluorspar, the carbon electrodes (made from petroleum coke), and electric power.

Theoretically the manufacture of aluminum is very simple. It consists of passing direct current through a molten bath of cryolite in which pure alumina is dissolved. To the electrolyte, that is, the solution of alumina in molten cryolite, flourspar or other fluorides may be added in order to reduce the melting point of the mixture below the temperature desired for furnace operation. The current passes from the carbon electrode through the molten material to the baked carbon lining of the furnace. The electric current brings about the separation of the metal from the oxygen in the alumina. The metallic aluminum which is deposited on the furnace lining accumulates in a molten condition in the bottom of the furnace, where it is protected from oxidation by the bath of cryolite above it.

Power Consumption.—In theory it requires only approximately five kilowatt-hours of electrical power to electrolyze out of a bath each pound of aluminum. Obviously, however, the current has much to do in the way of heating as well as electrolytic action.

The figures usually given in the literature for power consumption are 12.5 to 13 kilowatt-hours for each pound of aluminum.

Acid Extraction of Alumina.—The use of the Bayer process of alumina extraction requires the use of high-grade bauxite ores, low in silica. of which the domestic supply is not large. Moreover, aluminum is now produced only at such water-power sites as are easily available from the present sources of low-silica bauxite. Many power sites of the intermountain West could produce aluminum metal cheaply if a satisfactory source of aluminum oxide were available. Many of them are close to good supplies of clays or other aluminum silicates, and also to sources of sulphuric acid, which can be produced very cheaply because the sulphur dioxide from which it can be made is now being wasted in many places. In Utah, Arizona, and Montana combined the wastage of sulphur dioxide runs not into hundreds of tons but into several thousands of tons daily. In view of this fact the Bureau of Mines has engaged in a study of the use of sulphuric acid for the commercial extraction of alumina from silicious ores such as kaolin, leucite, alunite, glauconite, etc.—materials that are widely distributed throughout the United States. This country is one of the largest producers, and one of the largest potential producers, of aluminum and pure aluminum compounds. It is, however, increasingly dependent on bauxite imported from abroad (chiefly the Guianas, France, and Dalmatia) for raw material for the manufacture of alumina and aluminum hydrate for use in those industries. For political, as well as economic reasons, it would be well to develop processes looking toward the utilization of other aluminous materials within our own borders even if these processes are then only laid away for use in time of need. The Bureau, in its investigation, studies all the available literature bearing on the acid process of alumina recovery and concluded "that the cost of aluminum oxide made from clay by means of sulphuric acid treatment should rival the cost of the Bayer process oxide."[16]

Economic Characteristics of the Aluminum Industry.—The key factors in the aluminum industry are the cost of electrical energy and the transportation costs on moving the ore. The first requisite in determining the location of an aluminum reduction plant is to find a source of cheap electricity. Certain water power sites where the physical conditions favor low-cost development and where conditions do not favor the location of other industries that might bid more for the electrical power than aluminum can afford, offer the most favorable opportunities. The second requisite is a location which will permit cheap importation of ores to the plant. Third, the refining of the bauxite to alumina should be accomplished as near the mines as possible in order to avoid the transportation of unnecessary tonnages; a ton of crude bauxite ore reduces one-half or more in weight in the process of refining to alumina. In the United States the aluminum industry has selected water-power sites, at Alcoa, Tenn., Badin, N. C., Niagara Falls and Massena, N. Y. The factor of cheap water power is met at these sites, but they are not especially favored by cheap transportation. Further expansion at Niagara Falls and Massena is hampered by the growth of local industries and increase in the domestic lighting load, both of which can afford to pay more for electric current than can the aluminum industry. The ore calcining plant is located at East St. Louis, and the ore fields in Arkansas, near by. Thus the crude ore moves a short distance to East St. Louis to be calcined. The bauxite concentrate moves by rail to the various reduction plants.

Canadian Development.—The most significant event in the aluminum industry is the development in Canada; the estimates of pro-

[16] Tilley, G. S., Millar, R. W., and Ralston, O. C., Acid Processes for the Extraction of Alumina, Bulletin 267, Bureau of Mines, 1927, p. 81.

duction bear this out.[17] In order to appreciate the dominance of the Canadian sites the economic and geographic factors must be resolved into their simple elements. First, a water-power site capable of supplying electrical energy in large quantities is essential. Secondly, larger high-grade ore bodies than those existing in the United States must be used to adequately supply these large plants over a long period. Third, transportation costs must be reduced to a minimum, in other words, water transportation must be used. The requisite ore bodies exist in British Guiana and Dalmatia. Transportation is accomplished almost entirely over ocean routes. The water-power sites on the Shawinigan River and the Saguenay, especially the latter, were almost ideal. They are located in the British dominions, thus satisfying the law that ores mined in the British Empire must be smelted there. Then the sites are so placed as to permit a cheap ocean water haul. Both sites are located in a region where cheap labor is available and both can furnish hydroelectric energy cheaply in abundant quantities.

The Saguenay development will have a capacity equal to tne combined capacity of the other plants of the Aluminum Company of America. This river is the discharge for Lake St. John, whose waters are 300 feet above sea level. The river discharges through two outlets known as Petite Décharge and Grand Décharge. Utilization of this river began when the Price family, owners of pulp and paper plants in this locality, in association with J. B. Duke, built the Duke-Price hydroelectric plant at Île Maligne. This plant began operations in April, 1925, and is one of the largest single installations in water-power development ever undertaken. The completed plant will consist of twelve 45,000 vertical shaft turbines operated with 105 to 122.5 feet fall at approximately 112 r.p.m. Ten of these units are now installed. The power is used for pulp and paper manufacture, for electric lighting in Quebec, and for the aluminum plant at Arvida, 25 miles away.

The power is developed under almost ideal conditions since Lake St. John acts both as a natural reservoir and a regulator of the stream flow. The 540,000 Duke-Price plant, however, represents only a part of the river potentialities. Some 25 miles below Île Maligne, the Aluminum Company of Canada, Ltd., is planning the construction of another power plant which will utilize the second rapids of the Saguenay over a drop of approximately 200 feet. The entire flow of the river will be available providing a maximum output of three-quarters of a million horsepower. This plant, when completed, will supply the power needs of the aluminum reduction works. The aluminum plant itself is laid out to provide ultimately for 40 furnace rooms of 100 pots each. The

[17] Mineral Industry in 1927, p. 15.

output of the plant is, of course, governed by the available electric power. At the rate of 700 pounds of aluminum per kilowatt-year, the potential output of the plant is well above 250,000 tons annually. The Saguenay plant, in addition to its reduction works, also manufactures electrodes for its own use and for the plant at Shawinigan Falls, and a calcining plant which purifies the crude bauxite to alumina for both plants.

The World Aluminum Industry.—The aluminum industry is controlled by a relatively small group of producers in America and Europe. On the Continent, France, Germany, Switzerland, and Norway, are the most important producers while Italy is preparing for an expansion of the industry so as to join the list of countries with an exportable surplus of the metal. Prior to the World War there were only 13 aluminum-producing companies with a total of 23 manufacturing plants. Various interrelations among these companies have made for a high degree of centralization and cooperation. The five French companies, for example, are closely united in a holding company, L'Aluminium Français. The leading European concern, the Aluminium-Industrie A. G., at Neuhausen, operates and controls four plants in Switzerland, Germany, and Austria. Three firms in England and Norway are closely united. With the exception of France, the European producers are dependent upon foreign supplies of ore.

In 1926, the principal European producers united to form a cartel, the main purposes of which were to promote sales, stabilize prices, and effect lower costs of production. The development of sales has to do largely with the seeking out of new industrial uses for aluminum, both the pure metal and its alloys. Also, the various producing countries agree to refrain from competing in each other's home markets while foreign sales will be allotted by agreement. A further aim of the cartel is to effect closer relations with the branches of the industry manufacturing semi-finished and finished products.

A discussion of the domestic aluminum industry cannot be made apart from an analysis of the position of the Aluminum Company of America, the producer of practically all the pig aluminum in the United States and Canada. The beginnings of this company date back to 1888 when the Pittsburgh Reduction Company was organized with a capital of $20,000 for the purpose of experimenting with the Hall process of aluminum recovery.[18] The first reduction works was built at New

[18] For a review of the experimental work in aluminum reduction, culminating in the Hall process of electrolysis of alumina in a fused bath of cryolite, see Anderson, R. J., The Aluminum Industry, Chap. I, in Representative Industries in the United States, edited by H. T. Warshow, 1927.

Kensington, Pennsylvania, 18 miles from Pittsburgh. This plant produced about 75 pounds of metal per day in 1889, and the selling price was around $4.50 a pound. Many difficulties were encountered in the early days of the industry, as the metal was little known and its possible applications highly problematical, and the cost of production made the price almost prohibitive for industrial uses. In 1907, the name of the original company was changed to the Aluminum Company of America, which has subsequently become the largest and most important aluminum-producing and fabricating concern in the world. Although the first reduction plant was situated in the Pittsburgh district, on account of the necessity for large quantities of cheap electric power in the manufacture of the metal, the reduction plants have been built at places advantageous with respect to hydroelectric power, as at Niagara Falls, N. Y., Massena, N. Y., in North Carolina, and in Tennessee; also in Canada and Norway.

The Aluminum Company of American is the parent company of seventy-five subsidiaries engaged in mining, manufacture of primary aluminum and aluminum goods, transportation, selling companies, and miscellaneous activities incidental to the operations of the aluminum industry. Through its mining companies, owned wholly or in part, the Aluminum Company controls practically all the high-grade ore deposits in the United States and has holdings in Dalmatia, France, and British Guiana. It is engaged in the refining of crude bauxite in its calcining plants at East St. Louis and Arvida, Quebec, and in the reduction of alumina to pig aluminum in six plants in the United States and Canada, Norway, and Italy. It operates railroads to carry ore and concentrates. Several gas and electric public utility plants are owned wholly or in part.

CHAPTER XIX

LEAD AND ZINC

Lead has been called the "precious metal," and so it is if we measure a metal's preciousness by the number of its uses and its indispensableness in the goods that add to human comfort and welfare. Although exceeded in production by iron and copper, it is exceeded by iron only in diversity of usefulness and application. As a metal, an alloying agent, in chemical compounds, as an ingredient of manufactured goods, and an agent in industrial operations, the range of lead's usefulness is as wide as the field of industry itself. It is present in the home, in paint, pottery, glassware, and musical instruments; in the office, in typewriters, and calculating machines, in the various phases of transportation, the automobile, the airplane, and locomotive; in the building trades; the printing industry; the sportsman's rifle; and in the chemical laboratory.

World Lead Resources.—Lead deposits are widely distributed. Every continent except South America appears to be fairly well endowed with them, and even the meagerness of South American deposits may be more apparent than real. Twenty [1] countries annually contribute to the world's lead requirements although eight [2] countries supply over 90 per cent of the world's output. It is significant that a major portion of the output comes from countries near the world's industrial districts bordering the North Atlantic Ocean. North America supplies over half of the lead production of the world, and the United States accounts for 40 per cent.

Notable changes have occurred in lead production in the past two decades, changes which may indicate future importance in certain districts. Significant increases in output are shown in Canada, Mexico, and Burma, and equally important decreases have occurred in Germany, Greece, and the United Kingdom. The remaining producing countries show marked yearly fluctuations, but no definite trends toward increase

[1] Australia, Austria, Belgium, Bulgaria, Burma, Canada, Finland, France, Germany, Greece, Italy, Japan, Mexico, Rhodesia, Russia, Spain, Sweden, the United Kingdom, the United States of America, and the United States of South Africa.

[2] United States, Mexico, Australia, Spain, Canada, Germany, Belgium, and Burma.

or decrease. The United States evidently dominates the world lead industry, for it mines more lead ore, and consumes more lead than any other country. Part of the overwhelming predominance of this country as a consumer of lead is due to its large use of lead in paints, a use that is strictly prohibited by law in many foreign countries.

The relative importance of the important lead-producing countries is shown in Table XII.[3]

TABLE XII

LEAD PRODUCTION (TONS)

Country	Total, 1921–1927	Average, 1921–1927	Production in 1927
United States	4,200,431	600,063	700,684
Mexico	1,122,281	160,326	251,183
Spain	1,071,153	153,022	158,758
Australia	985,208	140,747	185,073
Germany	615,956	87,994	90,169
Canada	611,308	87,329	149,753
Belgium	529,451	75,636	97,003
India (Burma)	378,922	54,132	73,885
Italy	147,969	21,139	26,206
France	144,025	20,575	27,448
Total of above	9,806,704	93% of world total.	
All others	726,078		
World total	10,532,782		

From the standpoint of international commerce, the position of lead differs from that of many of the other non-ferrous metals in that most of the highly industrialized nations have within their political boundaries lead, mineable at a not abnormal price, in sufficient quantities to render them independent of other sources, at least for a time.[4]

Lead Resources of the United States.—Lead is produced in twelve districts in the United States of which three—the southeastern Missouri region, the Coeur d'Alene region, in Idaho, the Utah mines, and the Joplin district, Missouri, furnish 75 per cent. Other important dis-

[3] Data compiled from U. S. Bureau of Mines Economic Paper 5, "Summarized Data of Lead Production," 1929.

[4] For a detailed statistical analysis of the lead industry of the world since 1800, see the U. S. Bureau of Mines Economic Paper 5, "Summarized Data of Lead Production."

tricts are Bingham, Tintic, and Park City, Utah. The advances which have been made in the beneficiation of the complex lead-zinc-silver ores of the Rocky Mountain district have made available relatively large reserves of lead heretofore unavailable to commerce.

The Occurrence, Mining and Treatment of Lead Ores.—The mineral galena, a sulphide of lead, is the important constituent of most of the lead ores. The minerals, cerusite and anglesite, oxidized ores of galena, are also sources of lead. These constitute the only true lead ores and are found in abundance in southeastern Missouri. More frequently lead ores are found in association with other metals. Thus the zinc deposits of the Joplin district (Missouri, Kansas, Oklahoma) are really combinations of lead and zinc sulphides. A more widespread mode of occurrence of the lead minerals is a mechanical mixture with other minerals of other metals. These ores usually contain varying quantities of zinc, silver, gold, copper, iron, manganese, antimony, and bismuth. These types of lead ores furnish the major part of the nation's lead supply. They are represented by the lead deposits of Coeur d'Alene, Tintic, Bingham, Park City, and Leadville. The lead-silver ore is the type most frequently encountered in the Rocky Mountain districts.

The production of metallic lead from these various ores involves several operations nearly all of which are mechanical. Operations at the mine consist of crushing the ore to unlock the waste from the valuable portions screening to grade the broken ore, and concentrating to separate the valuable from the waste portions of the ore. Since the lead content in a ton of ore is very small, concentration is necessary at the mine before moving to the smelter.

Smelting the ore concentrates to extract metallic lead is accomplished with the aid of heat and a fluxing material. The simplest process consists of roasting, which oxidizes the sulphur and frees the molten lead. Such a simple process is restricted in its use, however, to high-grade non-silver ores of southeastern Missouri. Most of the ores carry silver, zinc, gold and copper, in addition to lead. These require, in addition to smelting, a process of refining whereby the associated metals are removed. Lead smelters and refineries are widely distributed over the United States, but with more or less concentration at industrial centers, notably San Francisco, St. Louis, Chicago, Pittsburgh, and in the vicinity of New York.

Properties of Lead.—Lead is among the heaviest of the common non-ferrous metals, a property which is valuable where momentum is required. It is soft, malleable, and ductile and can be easily made into sheet, bar, pipe, wire, etc. Because of its malleability the metal lends itself well to packing and calking. Its plastic nature permits easy bending of pipes and sheets into the form desired.

Alloyed with antimony and tin, it combines low melting point with sufficient hardness to make type metals or lead shot. Small amounts of barium and strontium added to the lead result in an excellent bearing metal. Its remarkable resistance to corrosion makes it a useful metal in chemical plants, in water fixtures of dwellings and office buildings and covering for electric cables.

Uses of Lead.—The wide variety of uses to which this metal is put may be divided into four groups, viz.,

1. Uses of the pure metal.
2. Uses in an alloyed form.
3. In chemical compounds.

Metallic lead is used in building construction for plumbing fixtures, roofing, and windows; in lead sheets for lining acid chambers, pipes, coils, etc. Because of its weight and malleability it is used in packing gas-pipe joints, in lead expansion bolts, in yacht keels, plumb bobs, sounding, divers' suits, sinkers; in hammers and anvils used in delicate work. Pipe organs require tons of lead each year in making pipes which support the column of vibrating air.

A still wider field of lead utilization lies in its alloying with other metals. In the electrical industry lead, hardened with a little antimony, enters into the storage battery. For this use alone more than 100,000 tons or one-eighth of the total lead output of the country is used. The twenty million or more automobiles in the country depending upon the storage battery to start their motors are examples of the usefulness of lead. As a protection against accidents in this electrical age lead enters into fuses, the safety-valves of the electric circuit. That useful instrument of communication, the telephone, carries its message in a lead-encased cable or wire. Also, it enters into the manufacture of light bulbs, spark plugs, and as a covering for electric cables and conduits wherever protection against moisture is needed. The engineer, in his efforts to reduce friction in running and rotating machinery, finds lead a useful ally. Every bearing tends to get out of alignment when strains are put upon it, or grit is likely to get into a bearing in spite of precautions. In either case, a hard steel bearing is out of the question and the bearing must be packed with a soft, yielding metal which can adjust itself to minute changes in the position of the rotating shaft, or allow the piece of grit to become imbedded in the metal. For this purpose babbitt metal, an alloy of lead and tin, is used. Another tin and lead alloy, solder, owes its usefulness to the interesting fact that it melts at a lower temperature than either of these metals alone and can, therefore, be used to solder both lead and tin objects. The canning industry, in which the cans are automatically sealed and soldered, is a sufficient indication of the importance of this alloy. Used in smaller quantities, but important because of the number of industries which are affected, may be mentioned the application of lead alloys in the printing trades, in ammunition making, in the manufacture of terne plate, and tin foil.

The various compounds of lead, taken together, form, by far, the largest single outlet for the lead-producing industry. Although the number of compounds is large and their use is varied, three are outstanding in quantity and utility. These are red lead, litharge, and white lead. Together they absorb half of the lead production. Red lead is brilliant scarlet red in color and is obtained in a number of grades, each grade having some particular use. As a paint pigment, it finds its most extensive use as a protective coating for metals subject to atmospheric influences. Other grades of red lead are used in glass making, in the manufacture of varnish, and in storage batteries. Litharge, a compound of 93 per cent lead and 7 per cent oxygen, is used in glass and varnish manufacture, similar to red lead, as an accelerator and controller in rubber vulcanization, in glazing pottery, and in petroleum refining. Orange mineral, a variety of red lead, but paler in color and finer in texture, is used in the manufacture of vermilion paint, printing ink, and dipping paint.

Of all lead compounds, none is so universally used as white lead. This substance is pure, refined, metallic lead converted chemically into basic lead carbonate. It is of importance as a paint material because of its opacity, its preservative properties, and its durability. It cannot be used as a paint, however, unless incorporated in some vehicle, commonly an oil, which dries into a hard surface.

Many salts of lead, other than the oxides find a wide variety of commercial uses for medicinal purposes, for textile dyeing and calico printing and in the manufacture of the pigment, chrome yellow. Lead arsenate is used largely as an insecticide. Other commercially used lead salts are lead nitrate, for dyes, basic lead sulphate, the latter being used largely in the rubber industry for tubing, hose, tires, and molded articles.

The Organization of the Lead Industry.—The production of commercially refined lead resembles in many respects that of the production of refined copper. In both instances the principal ore deposits are remote from the centers of consumption. Likewise, the ores of lead as well as those of copper are low in metallic content (less than 5 per cent in most instances) necessitating their concentration and smelting near the sources of production. Hence the location of lead smelters is frequently close to the mines. Finally, the product of the smelters still contains such metallic impurities as arsenic, antimony, tin, zinc, silver, gold copper, and bismuth, which are removed in the process of refining. Refineries are located both near the smelters and near the centers of consumption. The latter are found principally near Chicago, Ill., Omaha, Neb., Newark, N. J., and Carnegie, Pa. New York and St. Louis are the major lead markets.

Although the number of lead-producing companies is large and the industry would appear to be widespread among producers, more than 90 per cent of the mining output is in the hands of 25 companies and a like amount of the smelting is done by five companies.[5] The largest factor in smelting is the American Smelting and Refining Company with a smelter capacity of 3,330,000 tons. The important companies selling pig lead in the United States are:

American Smelting and Refining Company.
St. Joseph Lead Company.
United States Smelting, Refining and Mining Company.
United Metals Selling Company (controlled by Anaconda).
Des Loge Consolidated Lead Company.
American Metal Company.
Bunker Hill and Sullivan Mining and Concentrating Company.
The largest single purchasers are:
- National Lead Company.
- American Telegraph and Telephone Company.
- General Cable Company.

Economic Problems of the Lead Industry.—The lead industry, in common with most of the non-ferrous metals, began with the lone prospector and miner, locating surface deposits of high ore content which were mined and smelted in a crude fashion and on a small scale. The increasing demand for the metal was accompanied by a depletion of "bonanza" deposits and a need of resorting to lower-grade ores and the exploitation of larger ore bodies. The methods of the early miners no longer sufficed. Large expenditures for capital equipment became essential. Test boring to determine depth, size, and quality of an ore body was necessary. The exploitation of sub-surface deposits necessitated shafts and tunnels together with an underground transportation system to bring the ores to the surface. Moreover, elaborate and

[5] Warshow, H. T., Lead Mining and Smelting, in Representative American Industries, 1927, p. 374.

improved systems of concentrating and smelting the ore also demanded greater capital expenditures. The diamond drill for exploration work, improvements in milling, and the introduction of the flotation process made available to the large corporate organization lead ores which were utterly inaccessible to the individual miner. Selective flotation, which came into use in 1925, made the complex ores available. These advances in lead-mining technology have enlarged greatly the available reserves of ore in the United States, and, moreover, served to offset the diminishing lead content of ores by a reduction in the per ton cost of handling the raw ore.

Flotation and Selective Flotation.—The flotation process consists in the agitation of finely divided ore in water containing bubbles of air or gas and a small amount of oil and other chemical compounds. The oil and chemicals have an affinity for the valuable metals or minerals and coat the metal or mineral particles in preference to the gangue material. A second attraction of the oil and chemical compounds exists for the small bubbles of air or gas passing upward from the pulp mass. The result is that the metals or minerals are carried to the surface and form a scum which, when removed from the surface of the pulp, forms a concentrate of the metals desired.

Selective flotation is a further refinement of the flotation process in that it makes possible the separation of the valuable metals or minerals of complex ores.

Tariff.—In the development of the lead industry in the United States, the tariff has played a considerable part. A comparison of lead prices in London and the lead markets of the United States (St. Louis and New York) show a consistently higher price in this country. While this undoubtedly raises the price of the metal to the manufacturers of lead products, and indirectly to the consuming public, the tariff is defended on the ground that it stimulates the exploitation of the low-grade lead ores and, by bringing larger quantities of the domestic supply on the market, helps to reduce somewhat the cost of smelting. Moreover, without such protection, the production of ore and metal would undoubtedly be checked in times of depression.

Secondary Lead.—In the past many of the uses to which lead was put were entirely destructive or permitted only a very small percentage of recovery. These conditions are rapidly changing as lacquer and other materials are displacing lead as a protective coating and a greater quantity of the annual output is going into uses from which eventual recovery is large. About 90 per cent of the lead entering storage batteries is recovered after 30 or 40 months' use. Secondary lead is also obtained from babbitt, solder, type metal, and cable coverings. The recovery of secondary lead in 1926 amounted to 25 per cent of the total lead production for that year.

Future of the Lead Industry.—The useful properties of lead have served mankind since prehistoric times. The first authentic record of mining and smelting of lead ore in the United States was at Falling Creek, Va., in 1621 to supply ammunition, and for local uses. Lead was also produced in the Mississippi Valley and the eastern and southeastern states during the colonial period and the War of Independence. All these operations, however, were of little consequence, and at the beginning of the nineteenth century the industry in the United States could hardly be said to have begun. The first half of the nineteenth century was marked by a small output mainly from the mines of southwest Wisconsin. Decline of the Wisconsin mines marked a recession in lead output from 1845 to 1869. Completion of the first transcontinental railroad in 1869 gave great impetus to western mining activity, and with the discovery of the southeast Missouri deposits and the rapid development of the famous Jopkin district, production increased rapidly. With the opening of the twentieth century, the United States acquired a leading position.

The United States may be expected to maintain present production for some years to come, although its proportion to the total world output may decrease as a result of increased production elsewhere. Mexico undoubtedly has large undeveloped resources that will sustain an enlarged future production. The productive areas of Australia apparently have a limited life, and unless new deposits are found decreases may be expected. Spain has not as yet attained the pre-war rate of production, and future decreases may be expected. Canada will no doubt produce increasing amounts of lead in the future, as will Germany upon further development of the upper Silesian fields. South America is also believed to have possibilities as a future source of lead, but Belgium is not expected to increase production to any great extent.

ZINC

The Uses of Zinc and Zinc Compounds.—The chief uses of zinc are for galvanizing, brass making, and sheet rolling. Sheet zinc is employed in large amounts for dry batteries in automobile ignition, telephones, etc., and is of growing importance as a building material. In most structural applications sheet zinc may be replaced by the cheaper zinc-coated (galvanized) iron sheet; but where resistance to the atmosphere is the important requirement, pure zinc is used. Zinc spelter is consumed in the desilverization (refining) of silver-lead bullion. *Zinc dust,* a powdered form of metallic zinc, is used for sherardizing—a process of coating other metals with zinc. Large quantities are also employed in the dye industries and in the cyanide process of extracting gold and silver from ores. Zinc dust has a variety of minor uses through its extraordinary chemical activity as a reducing agent. *Zinc chloride*, a grayish-white solid, is used as a wood preservative, about 65 per cent of the domestic output being used for railroad ties. It is also employed in the manufacture of vulcanized fiber board and for pharmaceutical purposes as a caustic, astringent, antiseptic, disinfectant, and deodorant. *Zinc oxide*, a white insoluble compound of lead and oxygen, is the most important pigment containing zinc as the principal ingredient. When mixed with other pigments it is used in the manufacture of paint. It is also employed as an ingredient of vulcanized rubber goods and in the manufacture of oil cloth, linoleum, and printing inks. An especially high-grade zinc oxide serves in medicine and in many pharmaceutical preparations. *Zinc Sulphate* (white vitriol) is a colorless, transparent crystal or a white powder containing about 44 per cent water. It is used for preserving or clarifying glue solutions, as a disinfectant, as a mordant in the dyeing and printing of textiles, as an astringent and an emetic in medicine, and in electroplating. *Zinc sulphide* is a white or yellowish insoluble compound of zinc and sulphur. When combined with barium sulphate it constitutes the pigment lithopone. Zinc sulphide alone is seldom used as a pigment, but is employed primarily in the manufacture of dental cements.

World Distribution of Zinc.—The world production of zinc, since 1800 was over 37 million tons, two-thirds of which was derived from Europe. The greater part of this supply came from five countries—United States, Germany, Belgium, Great Britain, and France. During the nineteenth century Germany ranked first, with a production that exceeded the combined output of Belgium and the United States which ranked second and third. From 1901 on the United States was the leading producer, about equaling the combined output of Belgium, Poland, Germany, France, and Canada. In 1927 these countries produced 87 per cent of the world's zinc.[6]

The Zinc Resources of the United States.—This country is fortunate in possessing abundant resources of zinc. The ores mined to-day range all the way from $1\frac{1}{2}$ per cent in the Joplin district of Missouri to 25 per cent or more in some of the deposits of the Coeur d'Alene and other western districts.[7] Zinc occurs usually in association with lead ores or

[6] Consult Economic Paper 2, Summarized Data of Zinc Production, U. S. Bureau of Mines for a comprehensive summary of the world zinc industry.

[7] Leith, C. K., Economic Aspects of Geology, p. 214, 1921.

in complex ores of lead, silver, and some copper. There is only one important district in the United States, the Franklin Furnace district in New Jersey, which produces no lead. Zinc is mined in 23 states although ten states yield over 85 per cent of the total output. The three major provinces in the United States in the order of their importance are (1) the Mississippi Valley province, (2) the western province comprising most of the western States extending into Canada and Mexico, and (3) the Northeastern province containing the important deposits of Franklin Furnace, N. J., and the Adirondacks of New York.

A large part of the zinc ore produced in the United States has been supplied by the tri-state district, so called from its location at the junction of Missouri, Oklahoma, and Kansas. The greater part of the production of this district was first supplied by Missouri, but with the opening of the Picher field, about 1915, Oklahoma and Kansas became the more important producers. During the 5-year period, 1906 to 1910, this district produced nearly 50 per cent of the total mine output. In the next five years the output of the district increased only slightly, while that of the United States increased over 50 per cent. As a result the output of the tri-state district was only 34 per cent of the total for the period. In the next ten years the district increased to importance and produced 60 per cent of the United States output from 1921 to 1925. In 1927 the district declined to 48 per cent of the United States output.

New Jersey, the second largest producer of zinc ore in the United States, produced one-fourth of the total output of the United States from 1906 to 1910. Although New Jersey's production increased considerably, the increase for the United States, as a whole, was greater, so that the importance of New Jersey as a factor declined.

Montana has been the next largest producer since about 1915. Other western States with important productions are Utah, Idaho, and New Mexico.

Production of Zinc.—Zinc ores rarely contain sufficient metal to be sent from the mine directly to the smelter without concentration or enrichment. Concentration of lead and zinc ores was first accomplished by crushing and hand picking, but later gravity concentration by means of jigs and tables was employed and was generally used until a few years ago. This method depended solely on the difference in the specific gravity of the materials treated and was not entirely satisfactory, as the zinc and lead minerals often were closely associated with others of similar specific gravity from which they could not be cleanly separated. As the method of smelting lead ores differed widely from that of smelting zinc, one or the other metal was partly or wholly lost. In consequence, most of the complex ores were milled for the recovery of lead only, the zinc usually being discarded with the tailings. This wasteful practice prevented the economic treatment of many of the western complex ores; and in the tri-state district much of the finely disseminated zinc blende was lost in the tailings. In large part, however, these tailings have been successfully retreated by methods developed since they accumulated.

Three notable developments have greatly advanced methods of treatment. They are improvement in tables, magnetic separation, and selective flotation. Magnetic separation is successful in the treatment of coarsely crystalline mixtures of pyrite and blende but of little use in the treatment of galena-blende ores. Selective flotation revolutionized the art of ore dressing and almost relieved it of dependence on the differences in specific gravity of the materials treated. This process employs principles in a field of physics which is only partly explored by science and is not yet clearly understood.

Use of selective flotation has enormously increased the potential supply of zinc ore by making profitable the exploitation of complex ores of the West which formerly could not be utilized, also by increasing the recovery from tri-state ores. At first its use was handicapped by inadequate apparatus for fine grinding and for filtration. These handicaps have been overcome, and selective flotation is being adopted by nearly all the modern mills of Canada, Mexico and the United States. In the tri-state district flotation has been installed in the great majority of mills and is estimated to have added 15 to 18 per cent to the output of the district.[8]

The rapid introduction of selective flotation accounted for the rapid increase of supply of zinc concentrates in 1927 and nullified all efforts to effect a restriction of zinc output. Overproduction was reflected in a lowering of zinc prices.

[8] Stader, J. A., Zinc in 1926, U. S. Bureau of Mines, p. 228.

CHAPTER XX

MINOR INDUSTRIAL MINERALS

THE magnitude of industrial operations, especially in the United States, is reflected by the enormous tonnages of primary minerals and metals that are used. The complexity of manufacturing is emphasized when we survey the large numbers of mineral and metallic products that enter into the world's commerce and play their part in the production and fabrication of the almost innumerable commodities offered for our use. Compared with steel, copper, coal, or petroleum, the tonnage of other minerals is insignificant. Their importance, however, is not to be measured by tonnages, but by the many varied and indispensable functions and uses to which these minerals are put.

America's interest in these minor industrial minerals revolves around the problems that their production entails. Some of these minerals and metals are not found within the boundaries of this country, yet play a key part in important industrial operations. Others present special problems of mining and production in this country in competition with foreign supplies. Again, others are limited in quantity and the question of available substitutes is pertinent to the manufacturer-consumer. Among the more important of those that are of interest to this country is tin.

Tin.—America's interest in tin lies in the fact that she consumes more than half of the world's total output but has herself no domestic tin-mining industry and possesses no deposits of appreciable value. She is dependent entirely upon foreign sources for this metal.

Tin has certain unique characteristics which make it almost indispensable for certain industries. The atmosphere has little action on it and the metal is resistant to many substances, organic as well as inorganic, so that it is used largely as tin plate for making containers. Tin occurs in nature as an oxide (cassiterite) which carries nearly 80 per cent of the metal. The mineral is widespread throughout the world but only in a few localities is it concentrated in quantities sufficient for profitable recovery. These deposits are, with negligible exceptions, located far from the centers of consumption. About three-fourths of the world's supply comes from three districts, the Federated Malay States, the Dutch East Indies, and the Bolivian mines. The remainder is supplied by ten other districts or countries.

The world's leading producing area, the Federated Malay States, is part of a tin-bearing region extending from southwestern Yunnan, China, to the island of Singkep, Dutch East Indies, a distance of more than 1000 miles. Production in this area averaged 40,000 tons for the last twelve years or more and seems to show no signs of decline. Various estimates of its duration as a source of tin have been made but there seems to be little agreement among mining engineers on this subject. Undiminished output for a period of ten years with a decline to a much lower level for an indefinite period following is predicted by some British engineers.[1]

In the Dutch East Indies, the only other important producing district is the Straits Settlements, the output has remained about constant around 30,000 tons for the last six years. Here tin mining differs from that in other producing countries in that it is a direct government monopoly. On the islands of Banka, Billiton, and Singkep, tin has been mined for many years. The mining rights on these islands are leased for a term of years to companies that operate under government supervision and restriction. The reserves of the islands have been estimated rather carefully. From this estimate it is assumed that at the existing rate of production the reserves will last approximately twenty years. The policy of the Dutch government is to maintain output at a relatively constant rate, and there seems little likelihood that the Dutch will change this policy even though the demand for tin should increase decidedly.

The resources of the Unfederated Malay States are not known, but the production of approximately 2000 tons, year after year, will no doubt continue for some time. The developed deposits are relatively inaccessible and transportation difficulties retard development of others.

Bolivia, the only important producer of the western world, has gradually increased its tin output until it now ranks with the Dutch East Indies. The industry in this district labors under the handicaps of poor transportation facilities, lack of fuel, high cost of bringing in supplies, and inefficient labor. One-fourth of the present output comes from one mine, the Llallagna-Uncia, the largest tin mine in the world.

Other producers of tin are China, Siam, Nigeria, Australia, Cornwall, Congo, India, and South Africa.

The United States, as the greatest consumer of tin and the largest

[1] Furness, J. W., The Tin Situation from a Domestic Standpoint, Bureau of Mines Circular No. 6018, January, 1927.

manufacturer of tin and terne plate, is peculiarly dependent upon foreign countries for a supply of tin concentrate and pig tin. More than 50 per cent of the world's output is directly controlled by British interests, both governmental and private. Possibly 20 per cent more is indirectly controlled by the British smelting monopoly. The only major sources uncontrolled are those of the Dutch East Indies, Siam, and China, and of these a large part of the Dutch East Indies tin is now smelted by the Straits Trading Company (British) which also handles a part of the Chinese output, and resmelts and sells all of the Siam output. More than 98 per cent of the output of Bolivia is now smelted in Great Britain and Germany, under the control of a British-American-Bolivian company. Since the War, considerable tin has been purchased direct from the Straits Trading Company at Singapore, which bases its daily price upon the London and New York prices, as well as the needs of the purchaser.

Except in the Dutch East Indies, no evidence can be found that points to restriction of output by governmental regulation. Output or production is and has been limited by physical conditions as, for example, the utilization and appropriation of all water available in Siam, or limited transportation facilities, as in Bolivia. The Dutch in exercising control over a per annum output seem to take into consideration not only physical conditions such as available water, but possibly the fact that they have found the present per annum production gives them an economic advantage. Their position is extremely fortunate. Great Britain sets the price and for many years this price has been far in excess of the cost of production of Dutch tin.

Smelting.—At present the world's tin smelters have an annual capacity of approximately 175,000 tons of metallic tin. The Dutch East Indies smelt slightly more than 50 per cent of their output; the rest goes to the Straits Settlements for refining. The major part of China's output is now sold direct by the Chinese. A small percentage of the output of Siam is smelted locally; the remainder goes to the Straits Settlements. Less than 3 per cent of Bolivia's output is smelted in Bolivia and Chile. The National Lead Company of New York is associated with Williams Harvey and Company of Great Britain and the Patino interests of Bolivia in the control of smelters in Great Britain and Germany. This association handles more than 70 per cent of the Bolivian tin. With the exceptions mentioned, the rest of the world's production of tin is smelted by British interests. A new smelting plant now being constructed at Tandjong, Batavia, Dutch East Indies, will have a capacity slightly in excess of the total production of tin concentrates in the Dutch East Indies.

Export Tariffs.—The duty on tin ore exported from British Malaya is 73 per cent with an additional duty of $30, Straits, per picul on all ore exported to be smelted outside the British Empire. Thus the total duty is equivalent to about $375 (United States) per long ton. This duty was imposed to protect and maintain the smelting industry in Malaya. An American attempt to transfer this tin smelting to American soil and so obtain, in time, complete control of Malay tin products was frustrated by imposing a prohibitive duty on exportation of tin ore and giving an equivalent rebate on all ore smelted in the Straits colony. Smelting in the Federated Malay States is now handled virtually in its entirety, by two companies, the Straits Trading Company and the Eastern Smelting Company.

Uses of Tin.—Tin is used in the manufacture of tin and terne plate, solder, babbitt and bearing metals, brasses and bronzes, castings, type metal, foil, collapsible tubes, and chemicals. Tin plate is used chiefly in the manufacture of tin food containers. Terne plate is generally known as roofing tin and finds its principal use for this purpose. The amount of tin utilized in terne plate depends largely upon the coating of lead-tin alloy applied.

Substitutes for tin are appearing on the world's markets some of which, if successful, will effect radical changes in tin consumption. The substitution of aluminum for tin in food containers is reported in Germany. In this country an alloy of lead with small quantities of phosphorus and tin, known as Amaloy, is replacing the usual lead-tin solder in many uses. The large amount of tin used in the manufacture of food containers may be curtailed by the substitution of lacquered steel or other forms of protective coatings.

Fluorspar.—Among the minerals needed in the steel manufacturing process, fluorspar is assuming a place of ever-increasing importance. The commercial rise of this mineral is coincident with the rise of basic open-hearth steel for whose manufacture it is essential. Approximately 80 per cent of the total domestic production and imports are so used. Fluorspar (also called fluorite) is calcium fluoride and, together with cryolite, is the only important fluorine-bearing mineral occurring in commercial quantities. Deposits of fluorspar may be found in or near fault fissures as fillings, replacements of walls or sedimentary rocks near zones of faulting, as fillings in cavities, or as a residual deposits. With one or two exceptions its most abundant occurrence is in sedimentary rocks, most notably limestone.

An estimate of the fluorspar resources of the United States, much less of the world, is not available since no thorough prospecting of this mineral has been undertaken either by public or private agencies. A tentative estimate of the more important deposits can be made only from reports of the past and from present production. On this basis the largest fluorspar reserves of the world, in the order of their importance, are in the United States, England, and Germany. Other deposits are known to occur in Italy, France, Canada, and the Transvaal, South Africa.

United States.—Three states supply the bulk of the domestic fluorspar in this country, viz., Illinois, Kentucky, and Colorado. A small quantity is supplied by New Mexico. Illinois has yielded the greatest total quantity, but the mines have reached their peak and will no doubt decline appreciably in a few years. The Kentucky deposits have not been thoroughly prospected but it is safe to assume that the easily workable surface deposits have been discovered. This state will gradually displace Illinois as a source of domestic ore.

The Colorado output is considerably less than either Kentucky or Illinois but can be relied upon to supply local demand. No other districts in the United States show indications of possessing important reserves, although minor quantities are reported in several other states.

Industrial Fluorspar Needs.—Fluorspar is used in the manufacture of open-hearth steel, in foundry practice, glass manufacture, enamel, and making hydrofluoric acid. About 80 per cent of the domestic production and most of the imported fluorspar is used in steel making. The metallurgical use of fluorspar in the open-hearth process of steel manufacture depends upon its relatively low-melting point. It is added to the bath to render the slag more fluid so as to hasten the transfer of heat from the flame to the metal under the slag, thus shortening the duration of the heat. It is also said to aid in the elimination of sulphur and phosphorus. The steel industry uses an average of 7 or 8 pounds of fluorspar for every ton of open-hearth steel.[2]

Fluorspar is also used as a flux in the electric furnaces for the manufacture of steel, cast iron, and ferro-alloys, and has been found useful in the smelting of refractory ores of gold, silver, and copper. The uses of this mineral in other than the metallurgical industries are in making opaque white glass, colored or cathedral glass, hydrofluoric acid, and certain types of optical glass.

The United States is dependent for a considerable portion of its fluorspar requirements upon foreign imports, the bulk of the material coming from England and Germany.

Present knowledge of the world's fluorspar resources indicates that few districts can produce any very large tonnages. Some of these districts probably have already passed their period of maximum production.

[2] Bulletin 244, Bureau of Mines, pp. 59, 60, 61.

Consumption is increasing and new deposits are not being developed rapidly enough to maintain production at its present rate.

> Our resources should be carefully conserved by working narrow and low-grade veins in depth, by minimizing losses in milling, and by the efficient utilization of fluorspar for all purposes. To carry out the first two suggestions the market price of fluorspar must be high enough to give producers a profit commensurate with the risk involved.[3]

Asbestos.—The increasing importance of asbestos to modern engineering and mechanical practice, as well as the efficient construction of buildings, wherever heat insulation and fire protection are involved, mark asbestos consumption as an important index of progressive efficiency in the saving of heat. Asbestos is a term applied to any mineral that can be separated readily into flexible fibers. The properties that make asbestos valuable are fibrous structure, toughness, and flexibility of fibers, incombustibility, slow conduction of heat, high electrical resistance, and practical insolubility in ordinary acids. In the United States two minerals are mined and sold under the name of asbestos. Commercial asbestos falls into two groups, the spinning and the non-spinning fiber.

The largest use for spinning asbestos is for the manufacture of automobile brake bands and clutch-facings. This variety also finds its way in asbestos cloth for fireproof curtains, gloves, packages, and gaskets.

The short fiber and non-spinning varieties are used in shingles, wallboard, pipe coverings, paper, and millboard, and cements. Asbestos paper and millboard are used for heat and electric insulation in various ways. Millboard is used for making fireproof wallboard, lining, packing, etc. Asbestos shingles are being used to an increasing extent.

The principal sources of asbestos are the Quebec mines although the mineral is widespread in nature and production is reported in fourteen different countries and twenty districts. The province of Quebec, in Canada, produces nearly 70 per cent of the world's output and ships most of it to the United States. Although the latter country is the largest manufacturer of asbestos products, it produces less than one-half of 1 per cent of its requirements. The output in this country comes entirely from Arizona, Georgia, and Maryland; California, Montana, and Oregon are preparing to open mines. Small, but increasing quantities of asbestos are being obtained from Rhodesia.

Magnesite, Description and Uses.—Crude magnesite is a mineral which looks like chalk; chemically, it is carbonate of magnesium.

[3] Ladoo, R. B., Fluorspar: Its Mining, Milling, and Utilization, with a chapter on Cryolite, Bulletin 244, 1927.

The first step in its preparation for use is calcination, that is, a process of burning. Calcination reduces it to lump form and before being used it is reduced by grinding to a fine powder. It is prepared from the crude in two forms—dead-burned magnesite and caustic-calcined magnesite. The dead-burned variety, used as a refractory in metallurgical industries, is made from crude magnesite containing iron and is prepared by burning until all the carbon dioxide has been eliminated. The iron oxide acts as a binder. Besides its use as a refractory, it is also employed in heat insulation and as a filler and absorbent in paper manufacture.

Caustic-calcined magnesite is made from crude magnesite which is substantially free from iron. Calcination drives off most of the carbon dioxide. The magnesite at this stage is in the semi-manufactured form, known as lump caustic. It is reduced to fine powder for its chief use as plastic cement for stucco, flooring, and wall plaster. When carefully calcined magnesite is mixed with magnesium chloride and water in proper proportions, it sets and hardens like Portland cement, though much faster. This cement, known as Sorel cement, is used to an increasing extent in Pullman cars, hospitals, restaurants, schools, and other public buildings, and in the kitchens and bathrooms of private homes.

Domestic production of magnesite at present is limited to California which, from the beginning of production in 1886 to 1926, has produced over a million tons. Washington has a considerable deposit and is equipped with modern plants for production as favorable freight rates and tariff protection will justify operations. The foreign producers of magnesite are Austria, Greece, India, Canada, Manchuria, and South Africa. Greece and India are the principal competitors of the American product.

Platinum.—The Geological Survey has estimated the amount of platinum in existence at being approximately 5 million ounces of which the United States has about one-fifth.[4] This is about 425 short tons, or equivalent to the world's output of pig iron for three minutes, yet its indispensable importance in industry and research and its apparently limited quantity places it in the class of important industrial metals. Platinum belongs to a group of metals which, because of similarity of characteristics, must be considered together. These metals are platinum, iridium, palladium, rhodium, osmium, and ruthenium of which the first four are of commercial value. Pure platinum is used in large quantities in the "contact process" of making sulphuric acid and to some extent in the fixation of nitrogen. It is also needed in making utensils and apparatus for chemical laboratories whose importance to industry is

[4] Hill, J. M., Platinum and Allied Metals, Mineral Resources of the United States, U. S. Geol. Survey, 1916, Pt. 1, p. 1.

rarely appreciated. Finally, large quantities of platinum and iridium are used in electrical equipment, internal combustion engines, dental work, and jewelry. The so-called platinum used in electrical work is in reality an alloy of platinum and iridium. The contacts on the telegraph and telephone instruments are coated with this alloy. Palladium and palorium, an alloy of gold and metals of the platinum group, are finding their way as substitutes for platinum to some extent.

For the manufacture of sulphuric acid and nitric acid, and for use in the chemical laboratory, no satisfactory substitutes are known. Concentrated sulphuric acid is essential in the manufacture of explosives, acids, chemicals, and directly and indirectly, of almost everything else; it may be said to be as fundamental as iron itself. One begins to appreciate the important rôle of platinum in our industrial operations.

The supply of this metal was long monopolized by Russia and Colombia although, in recent years, South Africa came into prominence as a source of platinum. For many years the world's principal source of platinum was the Ural Mountains of Russia. In 1913 this district supplied 93 per cent of the world's output. The War interrupted platinum mining in this district so that production fell off from 202,000 troy ounces in 1913 to 5500 troy ounces in 1921. The years following witnessed a gradual increase to about 90,000 ounces. The post-war position of Russia in the platinum industry was strengthened due to the fact that all platinum mined within the country is also refined there, whereas in 1913 only 5 per cent of the Russian production was domestically refined.[5]

The only other platinum producer of importance is Colombia. While its production in 1913 was less than 8 per cent of the world's total, in 1926 it rose to about 40 per cent.

Considerable interest and active exploration resulted from the discovery of platinum in the Union of South Africa and in Southern Rhodesia. Actual output of the metal in these districts is still insignificant and its potentialities are still unpredictable. Present indications do not warrant the conclusion that Africa will become a leading producer.

The production of platinum in the United States is insignificant. Under the stimulus of a high war price, production rose to 10,000 ounces but declined immediately with a fall in prices. Production in the last few years has averaged about 4000 ounces annually. There seems to be small prospect of finding important domestic resources. Like tin, it is a metal for which this country is entirely dependent upon foreign sources.

Antimony belongs in a class with tin, manganese, asbestos, nickel, and platinum, in that the United States has only a negligible reserve of the commercial grade. While its uses are many, the quantity required is not large and it remains in the class of minor industrial metals. Although 14 countries reported production in 1927, about 85 per cent of the world's supply comes from the Province of Hunan in China. Of this, the United States takes 80 per cent. Thus it appears that China is the largest producer and America the largest consumer of this metal. Metallic antimony unalloyed has few uses. As an alloy it is a standard constituent of white-metal alloys of low melting point, such as type metal, britannia metal, and stereotype metal. It alloys readily with most of the heavy metals and the alloy is harder than either of the two pure metals. Most of these alloys possess the property of slight expansion upon solidifying. The most common alloying metals are tin, lead, and copper. Babbitt metal, an alloy of copper, tin, and antimony, is the largest user. Sixty-five per cent of the imported antimony is used directly or indirectly in the automobile industry in the form of bearings or storage batteries.[6] Other uses are found in cheap domestic tableware, cable coverings, fuses, and acid-resisting valves. The greatest single use occurred during the War for the manufacture of bullets and shrapnel. In the form of antimony oxide, its chief use is in the making of white enamel and glass, coloring agents, and pigments. The sulphide form is used in vulcanizing and coloring red rubber and also in paint pigments.

The importance of China as the major source of this metal has led to a study of possible reserves. Estimates made by Tegengren place a figure of 1,300,000 tons of metal still available in the Chinese fields with an additional 150,000 tons present in ores now too low grade to be mined. Since this country supplies about 18,000 to 20,000 tons annually at a cost below that of its competitors, it seems destined to remain the principal producer for many years.[7]

Mica is a common rock mineral, but is commercially available only in certain types of igneous rocks of coarse crystallization so that the mica crystals are exceptionally large. Two varieties of mica are of particular economic importance—muscovite or white mica, and amber mica. Mica is unique among minerals in possessing a combination of properties that make it indispensable in the electrical industry, where it is used as insulating material. In no other mineral are there combined the properties of easy and regular cleavage, great flexibility, elasticity, transparency, nonconductivity of heat and electricity, and general resistance to decomposition. Sheet mica is essential in the manufacture of electrical machinery—radio condensers, magnetos, tele-

[5] Russian Platinum in 1927, Comm. Repts., March 19, 1928, p. 756.

[6] Li, K. C., Antimony, Mineral Industry in 1926, p. 48.

[7] Bain, H. F., Ores and Industries of the Far East, 1927, p. 151.

phone equipment, spark plugs, electric light sockets, fuse boxes, etc. Although many attempts have been made to develop insulating materials that could be manufactured and substituted for mica at less cost, experience has shown that these substitutes do not possess all the properties of mica; their use has heretofore been restricted and has not presented serious competition.

Mica which is not suitable for use as sheet is classed as "scrap." It is ground to a powder and used in the decorative trade in the manufacture of wall paper, fancy paint, ornamental tile, and concrete facing, and for other purposes; as a lubricant, both dry, as for auto tires, and mixed with oils and greases, for axle grease; for annealing steel; as a dusting agent for rolled roofing; as an insulator for pipe and boiler covering; and fireproof paint.

Production of mica is carried on in nine states, North Carolina, New Hampshire, New Mexico, South Dakota, Virginia, Georgia, Colorado, South Carolina, and Connecticut—named in the order of their importance. Considerable quantities are also imported from Madras and Canada.

Mercury, or quicksilver, is familiar to all of us who daily look at the imprisoned column of this liquid metal in the thermometer or barometer to find out the temperature or atmospheric pressure. As a matter of fact, only a small percentage of the yearly output of mercury enters into instruments of this kind. It has wide and varied uses in industry, an enumeration of which would be rather tedious. The uses may, however, be gathered into a few representative groups which will serve to indicate the nature of the functions that mercury performs. These groups of uses are: As a constituent of drugs and chemicals, as a detonator, other uses.

The major part of the mercury consumed in this country finds its way into drugs and chemicals, important of which are calomel, corrosive sublimate, and red precipitate, or mercuric oxide. Calomel and corrosive sublimate find their chief use in medicine and as an antiseptic respectively, although the latter has varied uses in cloth printing, photography, and as a wood preservative also. Mercuric oxide finds an important use in the preparation of anti-fouling paint for ship bottoms.

The use of mercury fulminate as a detonator has expanded considerably with the increased use of military and industrial explosives. It is estimated that 4000 flasks of 75 pounds each were so used in 1926.[8]

In addition to the above uses which absorb probably three-fourths of the metal, it has a varied use in dental amalgams, scientific instru-

[8] Furness, J. W., Mercury in 1926, Mineral Resources of the United States, 1926, Pt. 1, p. 131.

ments, electrical equipment, radio, gold and silver recovery, in the manufacture of certain dyes, felt making, and in the coloring of hard rubber. The mercury vapor boiler, still in the experimental stage, may in the future require large quantities of the metal.

Occurrence of Mercury.—Practically all of the mercury produced comes from the bright red sulphide known as cinnabar. Pure cinnabar contains 86.2 per cent of mercury. Mercury ores are widely distributed throughout the world. Although the greatest number of known occurrences are in Europe and in western North and South America. Ore bodies are very irregular in form and, hence, difficult to estimate quantitatively.

Producers of Mercury.—The largest and richest deposit of mercury now known in the world is at Almeden, in central Spain. The ore bodies are large and development has extended to a depth of 2000 feet. The available reserve is estimated as at least 40,000 metric tons.[9] Next in importance to the Spanish deposit is the one at Idria and Monte Amiata, Italy. As in Spain the mines are owned by the government. The mines of Idria have been worked for a long time and appear to be reaching exhaustion; the Monte Amiata district seems capable of maintaining its present output for 20 years more.[10]

The third largest producer of mercury is the United States, but its output is only about 8 per cent of the total world production. Total output of the three countries in 1925 was 3100 tons of which the United States furnished 312. All other countries make but a small contribution to the world's total. Development in other districts has not been retarded by high costs of production, but rather the fact that deposits large enough to warrant exploitation have not been discovered. Of the minor sources, Japan, Austria, China, and Russia are the most important contributors.

Mercury Deposits of the United States.—As previously stated, domestic production of mercury is small; it supplies about one-fourth of the annual needs. The principal producing state is California, which furnishes from 70 to 80 per cent of the total. Texas is the only other state contributing an appreciable supply, and small quantities come from Idaho, Nevada, Washington, Alaska, and Arizona—from a total of 17 mines. Domestic reserves of the metal have never been estimated but a fair inference from the history of production seems to be that the reserves at the present price are being rapidly depleted, for production is decreasing and prices are rising. High-grade mines of mercury in the United States are conspicuous by their absence. Unless new methods which

[9] Furness, J. W., Mineral Resources of the United States, 1925, Pt. 1, p. 47.
[10] Furness, J. W., Mineral Resources of the United States, 1925, Pt. 1, p. 50.

will enable ores of lower grade to be worked profitably are devised, the domestic demand can be satisfied economically only from foreign sources. To the consumer the existing situation would seem to indicate that in order to supply the demand for mercury the deposits of Spain will have to be drawn upon heavily. Of the two Italian fields, the Idria district is rapidly reaching exhaustion; the Monte Amiata district may be able to maintain its present rate of production for 20 years.[11]

Gypsum is a natural hydrated sulphate of lime. The principal uses of this mineral are as structural material and as an ingredient of Portland cement. Gypsum wall plaster is in common use, and gypsum boards, blocks, and tile are fast making a market because of light weight, convenient, and fire-resistant qualities. When calcined between 100° to 200° C. in kettles, or rotary kilns, it loses three-fourths of its combined water content, forming a white powder, which, when ground, is known as plaster of Paris. In this form it is used for dental plaster, plaster casts, plaster molds, especially in the ceramics industry, for imbedding plate glass when polishing, and for stucco in buildings. Plaster of Paris, with small quantities of retarder and hair or fiber, is used as wall plaster.

Gypsum is produced in 18 states, although 90 per cent of the product comes from New York, Iowa, Michigan, Texas, Ohio, Nevada, Oklahoma, and Kansas, in the order named. The most extensive deposits are in Wyoming, Utah, Texas, and New Mexico, where thick beds of high-grade gypsum crop out for hundreds of miles. In Wyoming alone gypsum beds from 6 to 20 feet thick are exposed for a thousand miles and constitute a reserve that the world's demands could not exhaust in many decades.[12]

[11] Furness, J. W., Mineral Resources of the United States, 1925, Pt. 1, p. 50.

[12] Bulletin 666, U. S. Geological Survey, 1919, p. 70.

CHAPTER XXI

THE MINERAL FERTILIZERS

THE farmer tills the soil that plants may grow and man may live. This is apparently a simple statement, yet, until we consider the numbers of goods which are derived from the soil, we are unaware of our utter dependence on this thin mantle of soil covering the outer crust of the earth. Our first thought is that of the earth as a source of food supply, but we soon learn that many of the raw materials of clothing, shelter, and the conveniences and luxuries of life also come from that same storehouse. Thus we count rubber, cotton, lumber, paper, tobacco, hemp, paint oils, chemical and medical products whose ultimate source is the soil.

The media through which the elements of the soil are converted into useable goods are the plants and, indirectly, the animals. Plant growth is essentially a building process. The raw materials of the plant structure—carbon dioxide, nitrogen, mineral elements—are found in the air and in the water solution of the soil. In a sense the soil may be likened to a factory. The tiny rootlets of the plant gather in the solution of mineral salt, the leaves inhale oxygen and carbon dioxide, and the energy of the sun working in conjunction with the chlorophyll of the green leaf constructs starches, celluloses, sugars, and proteins, the building blocks of the plant. In some instances the building process consists of many steps. Forage crops composed of inedible carbohydrates such as cellulose are fed to cattle who serve to transform the hitherto unavailable materials into edible proteins and carbohydrates, meat or milk.

Although plants occur in a multitude of different forms and species and grow upon diverse types of soil, they are all made up of a very few chemical elements and all are fairly similar in chemical composition. Hence, of the ninety odd elements that compose the earth's crust only ten are required to satisfy the needs of the growing crop. These are carbon, hydrogen, oxygen, phosphorus, potash, nitrogen, sulphur, calcium, iron and magnesium. Carbon is obtained from the carbon dioxide of the air, hydrogen and oxygen are obtained from water, nitrogen is obtained immediately from the organic residue of the soil although its ultimate source is the air, of which it constitutes four-fifths. The remaining elements are obtained from the minerals of the soil. Of these ten elements, nitrogen, phosphorus, potash, and probably sulphur are present in quantities so limited as to prevent the maximum growth of vegetation upon the soil. These four constitute the so-called mineral fertilizers, that group of elements which the farmer adds to the soil for the purpose of increasing crop yields.

Nitrogen, in its elemental form, is present in abundant quantities in the air. Above every acre of the land there are 70,000 tons of this element. The higher-order plants such as the common field crops cannot, however, make use of this atmospheric nitrogen, even though they are surrounded and enveloped by it during their entire period of growth. Atmospheric nitrogen must first be absorbed and utilized by lower-order microorganisms. These decay in the soil and thereby supply nitrogen in the soil in a suitable form for absorption by the rootlets of the higher plants. The present supply of soil nitrogen, then, merely constitutes the debris of thousands of generations of plants and since man's cultivation of the soil began, has been undergoing constant depletion.

Potash is another essential for plant growth. The general tone and vigor of the plant are largely based upon an ample supply of this element. The popular expression that "potash makes starches and sugars" is a fairly accurate statement of its function in plant tissues. While the element itself is not a constituent of any carbohydrate compound, it is in some way connected with their manufacture in plant cells.[1] The potash content of soils, compared with nitrogen and potassium, is high. Quantities up to 50,000 pounds per acre are not uncommon. Nevertheless, it is very frequently in a form unavailable to the plant, and for purposes of plant growth may as well be absent. For this reason the farmer finds it necessary to add soluble potash salts to the soil so that the growing crops may be properly nourished.

Phosphorus is also an extremely important element in plant nutrition. It is a constituent of most proteins, particularly those which are found in the nucleus of cells and seems to have some definite relation to cell division and multiplication in growth. Phosphorus is the least abundant of the plant food elements. In many of the soils of the United States, it constitutes the limiting factor in plant growth. Moreover, it is the element which is drawn upon most heavily and is found in the greatest proportion in that part of the plant which is sold from the farm. Unless replenished, phosphorus exhaustion will occur earlier than any of the other critical elements.

Sulphur seems to serve a purpose similar to that of phosphorus, but

[1] Thatcher, R. W., Chemistry in Agriculture, p. 9.

its exact use is not known. Although it is frequently no more abundant in the soil than phosphorus, it is not required in such great quantities by the growing plant. Sulphur is rarely applied to the soil directly as a fertilizer, but is added in acid phosphate, of which it is an important constituent.

The Economic Function of Fertilizers.—That the present methods of cropping are depleting the soil of its original supply of plant food leaves no question regarding the ultimate necessity of adding plant food to replenish this loss. Because this annual drain on the fertility of the soil is not being promptly replaced, the cry of soil exhaustion is being sounded, the farmer is charged with wasting the nation's most precious asset, and is warned, for the sake of the future, to replenish the soil with fertilizers. However, the farmer is interested in fertilizers only if they serve to increase his income. Certainly he is not interested in such proposals as conserving the soil at its original level of fertility merely for conservation's sake. To the agricultural industry the question of fertilizer use is plainly one of economic advantage. In the event that a growing population demands more food than the farms now produce, the farmer will find it profitable to meet that increased demand by using fertilizers. Thus, conservation of soil fertility when it is needed, will probably be accomplished in conjunction with increasing food production.

If the economic function of fertilizers is to increase the farmer's profits what, then, are the economic conditions that surround their use? This problem should be approached both from the viewpoint of the individual farmer and from that of the entire agricultural industry. The economic advantage to the individual farmer can be expressed in terms of labor. "The following considerations indicate in a semi-quantitative way, the labor saving to be made by the use of fertilizers. Studies in the United States Department of Agriculture show that the total labor of producing corn if harvested from standing stalks is 19 hours per acre on the average; for oats 13 hours per acre, and for cotton 128 hours per acre. Twenty-five years of experiment with fertilizer in a five-year rotation at the Ohio Agricultural Experiment Station gave the following increases in production due to fertilizer: Corn, from 28.06 to 42.97 bushels per acre; wheat, from 11.43 to 22.76 bushels; oats, from 32.07 to 45.22 bushels; and the Mississippi Experiment Station found that use of fertilizer increased the cotton yield in a given case from 691 to 1096 pounds. Assume for the moment that the labor per acre was not increased by the larger crop. The increased labor efficiency would then be: For corn, from 1.48 to 2.26 bushels per hour, or nearly 100 per cent; for oats, from 2.47 to 3.48 bushels per hour, or about 41 per cent; and for cotton, from 5.4 to 8.56 pounds per hour of labor, or nearly 59 per cent. The actual increases of labor efficiency will be a little smaller than those indicated above, for the larger crop will require more labor to harvest. Since, however, the preparation of the soil for planting, the drilling of the seed and fertilizer, and the cultivation of the crop will be the same regardless of yield per acre, it is at once clear that an increase in labor for harvesting alone can create only a small percentage increase in the total labor of producing a crop, and, therefore, the increases in labor efficiencies given above are only slightly higher than the actual average results for the given data. This phase of the situation is of particular interest at present when farm labor is relatively high priced and hard to get. It appears that there is really a great opportunity to hold production of food crops per man at a high level by intelligent use of fertilizers if these can be bought at a price less than their equivalent labor value."[2]

The economy of fertilizer use, so clearly demonstrated above, in the case of the individual farmer, assumes a different aspect if applied to the entire farm area. The universal application of fertilizer to the farms of the United States today would probably result in a surfeit of crops and consequent low prices so as to defeat the very purpose of their application—increased profits. The present problem of the farmer as a food producer is not one of population pressing upon food supply but rather that of food supply pressing upon population. The way out of this unprofitable status of the industry is not to be found in refraining from the use of fertilizers. The first step, and one already in progress, is the abandonment of lands of low fertility, those lands upon which the crop-yield per hour of labor is low and which will respond least readily to fertilizer application. In this class will be found much of the irrigated land, land in the semi-arid regions, poorly drained, rough, stony, and sandy lands. These may well be returned to forests or permanent pastures in which capacity they will find their highest economic use. Even with the return of lands clearly unsuited to arable agriculture, the productive capacity of the arable lands would, in all probability, outrun present demands. This condition is admittedly temporary and changing conditions will require altered farm practices. A growing population will eventually wipe out the possibilities of recurring farm surpluses and gradually exert an increasing pressure upon land supply. Higher land values will ensue as more food is needed. If an attempt to meet this increased demand follows the practices of the past, then the boundary of arable lands will attempt to encroach upon the pasture

[2] Curtis, H. A., Nitrogen Survey, Part II, Trade Information Bulletin 226, Bureau of Foreign and Domestic Commerce, 1924, pp. 9, 10.

and forest lands, the desert lands, and the undrained areas now lying unutilized. This expansion will meet difficulties measured in terms of increasing costs of subduing and improving this lower-grade land and bringing it into production. The experience of farmers on the irrigated lands of the Mountain States, on marginal cut-over lands of the Lake States—Michigan, Wisconsin, and Minnesota, for example—indicates that this high-cost, second-rate land cannot be farmed profitably. The alternative is a more efficient and intensive use of the existing high-grade lands in the heart of the agricultural districts of the country. The experience of the future may show that the application of fertilizers to high-priced lands of excellent physical make-up and high fertility will yield a greater net return than a similar application to the sandy or marshy soils, or in regions handicapped by short growing seasons. There will be an increasing spread of value between high-grade lands and marginal lands and an increasing concentration of food production on the former. Fertilizers on these lands will become a permanent part in the farmer's program of production. The day of expansion of the farming areas, such as was witnessed in the closing decades of the previous century, has come to an end. An increasing volume of food supply is contingent upon supplying the farmer with cheap fertilizers, as cheap as chemical and manufacturing technique can produce them, and this is particularly true of nitrogen.

The technique of efficient soil management is a complex one. Fertilizer use constitutes but one of the problems that will engage the attention of the farmer. Proper drainage, crop selection and rotation, methods of cultivation, plant breeding, weed, disease, and insect control all require the vigilant attention of the husbandman. Far-reaching changes may also be expected as the mechanization of farm operations is carried beyond its present state. Scientific management applied to agriculture is yet undeveloped. These problems, however, are beyond the scope of the present discussion. Attention will be confined to a study of the contribution of fertilizers to the productive problem. The characteristics of the minerals of the fertilizer group are so diverse that each must necessarily be treated separately. Nitrogen will receive first consideration.

NITROGEN

It may seem curious that plants should suffer for want of nitrogen when, in the earth's atmosphere, enveloping all plant life, there is a gaseous blanket containing upwards of 4000 million million tons of nitrogen. The difficulty lies in the fact that this nitrogen is inert and in a form which is not suitable for absorption by the tiny rootlets of the growing plant. Before it can be used as food by the plant it must be combined with some other element or elements to form a soluble salt.

The present supply of soil nitrogen is merely an accumulation of air nitrogen fixed in the soil over a long period of years. The gateway through which the nitrogen of the air must pass into the soil is a narrow one indeed. Very likely the first entry was provided by a group of microscopic plants, the nitrogen-fixing bacteria, who have the power to assimilate nitrogen in its elemental form and combine it into a liquid or solid, to be used by the higher plants. The work of these bacteria served to widen the door through which nitrogen might enter; for certain other types of bacteria living in close relationship to plants of the legume family also absorbed and converted free nitrogen. It is not improbable that other plants may show nitrogen absorption to some degree but it is safe to assume that the avenues of entry of free nitrogen into the life cycle of plants are very few. The return of nitrogen to the air, on the other hand, is accomplished in a multitude of ways. Denitrifying bacteria in the soil, leaching of soils and animal manures, the removal of crops, the decay of prairie and forest vegetation, the present methods of sewage disposal, the burning of coal and wood, the coking of coal, all provide means for the release of fixed nitrogen. So enormous are the losses occasioned by modern agriculture and industry that only through conscious replenishment by man can a supply adequate for plant growth be maintained.

There are at last seven sources from which plants are securing nitrogen. These are classified by Curtis as follows: [3]

1. Nitrogen compounds carried down by rain and snow.
2. Nitrogen captured from the air and "fixed" by bacteria living in the soil or on the roots of legumes.
3. Animal manure, both that produced by domestic animals and that secured from deposits such as the guano found on the islands off the coast of Peru.
4. Nitrogenous waste materials such as cottonseed meal, meat packers' scrap, fish scrap, etc.
5. Sodium nitrate from Chile.
6. Ammonium sulphate produced from coking of coal.
7. Free nitrogen synthetically fixed by chemical processes.

The nitrogen carried down by rain and snow has been the subject of measurement and, although the quantity varies from place to place, it is

[3] Curtis, H. A., Where the Nitrogen Comes From, Chemistry in Agriculture, 1926, p. 77.

roughly around 5 pounds per acre per year.[4] Since a 25-bushel crop of wheat removes nearly 50 pounds of nitrogen, it is evident that this source of supply is wholly inadequate to maintain a sufficient nitrogen reserve in the soil.

Another source of nitrogen in the soil is that captured and "fixed" by certain types of bacteria. These microorganisms fall into two classes, the azotobacter and the symbiotic bacteria. The former are able to gather nitrogen into the soil independently of any association with other forms of plant life. The symbiotic bacteria are associated in their life processes with a group of plants known as legumes of which alfalfa, clover, vetch, peas, and beans are important examples. The amount of nitrogen fixed by bacteria is enormous compared with that which enters the soil by other natural means. The symbiotic bacteria are the more important of the two groups for in regions where soil conditions, rainfall, etc., permit the growing of legumes these crops provide a method of returning to the soil a part of the nitrogen removed by other crops. In some localities possibly all of the nitrogen required may be met by use of such crops, particularly where they can be grown as catch or cover crops between the regular annual crops. "It does not appear, however, that the growing of legumes can for a moment be considered as a general solution for the problem of nitrogen supply in American agriculture. Where legumes are raised in a regular rotation of crops on a three- or four-year schedule it is not profitable to plow under the whole crop. Since a legume crop is harvested as livestock feed, it is evident that only by a very large increase in our livestock production could the legume crop be utilized should one-fourth of the total cultivated area of the country be in legumes annually. An urge for increased food production, however, inevitably drives agriculture toward direct human food crops, the grains, and away from livestock production. Further, there are many sections of the country where rainfall is the limiting factor in crop production, and since some legumes have a very large moisture requirement, they can not be grown in such sections. This condition obtains over much of the wheat-growing areas of the United States. A further deterrent to the wider use of legumes is the fact that many legumes require a soil free from acidity and in order to raise legumes on many of our soils it would be necessary to make a heavy preliminary application of lime. This expense and the subsequent one of raising a low-value legume crop may render this method of nitrogen to the soil unprofitable."[5]

[4] Lipman, J. G., The Nitrogen Problem in Agriculture, Amer. Fert., Feb. 4, 1928, p. 32.

[5] Curtis, H. A., Nitrogen Survey, Part II, Trade Information Bulletin 226, Bureau of Foreign and Domestic Commerce, 1924, p. 12.

Nitrogen from Organic Sources.—The most important present sources of nitrogen, as well as phosphorus and potash, on the farms of the Middle West is barnyard manure. Since this is originally derived from the plants used as food by the farm animals it is only a means of returning to the soil a part of the nitrogen reserve and such a process can never increase the store of nitrogen in the soil. The supply, moreover, must necessarily decrease as the increasing food demand of the world drives agriculture more and more toward direct production of human foodstuffs. Nitrogen has also been supplied from such sources as fish scrap from the sardine industry. Cottonseed meal is another common fertilizer ingredient, along with meat packers' scrap, tobacco stems, dried blood, and a wide variety of such materials, known to the trade under the term "organic ammoniates." All such materials are of value as fertilizer primarily for their nitrogen content, which, unfortunately, is usually low. Many of them are finding more profitable use in stock food and their importance as fertilizers is diminishing.

The foregoing sources of nitrogen, while their aggregate contribution is large, are insufficient to meet the world's nitrogen needs for agriculture and for other purposes. In increasing amounts, the nation must draw upon inorganic sources to satisfy its mounting nitrogen needs. There are three sources from which this supply is now being obtained. These are Chile nitrate, by-product ammonia from coal, and synthetic or "air-nitrogen" sources.

Chile Nitrate.—For nearly one hundred years Chile nitrate has been used as a source of agricultural nitrogen. Beginning with a thousand tons in 1825 the output has increased to 3,360,000 tons in 1928. The nitrate deposits are located in a long narrow strip of territory, on the eastern slope of the coastal range of Chile, in the desert country lying between the coastal ranges and the Andes. The nitrate occurs in patchy deposits or beds, 4 to 12 feet thick, usually overlain by several feet of sedimentary deposits. The ore, known as caliche, is dug and transported to plants where the sodium nitrate is extracted by leaching with water. The water solution is evaporated and the nitrate salt dried and transported to the coast for shipment.

The Nitrate Deposits.—The actual zone in which nitrate is found extends from the northern border of Chile to the region of the Caldera in the south, an area nearly 500 miles long and less than 100 miles in width. This zone comprises four of the provinces of the States of Chile: Tarapaca, Antofagasta, Atacama, and Coquimbo. Mountains and ocean meet so abruptly that most of the little port towns appear to be on the verge of toppling over into the sea. So small is the level area that in numerous cases the streets can be laid out only in a north and south direction; cross streets are blocked at one end by the mountains and the other end by the sea. Although the coast ranges of the Andes is but a fraction of the height of the Andes proper, it presents a spectacular bulwark upon which a heavy ocean surf constantly breaks. Between this range and the main Andes there extends a great shelf-like and in many parts a rather level plain, varying in altitude from 3600 to 10,000 feet. In this plain some nitrate deposits lie within 15 miles of the sea, but farther south the product is found 30, 40, or 100 miles inland.[6]

Extreme aridity has favored the preservation of these easily soluble nitrogen salts. Rain is rare; light showers may fall in a year but heavy precipitation comes but once in 6 or 7 years. The coast is washed by the Humboldt current, an ocean stream having its source in the Antarctic, and when the wind blows toward the land they are cooled by the cold water to a temperature below that of the land, so that no moisture precipitates. Winds from the east are forced to high altitudes by the Andes, and hence deposit their moisture on the east side of these mountains. As a result, the coast and the valley east of the coast range receive practically no moisture, making them what is perhaps the driest region in the world. It is in such circumstances that the crude nitrate, or "caliche" is found.

The nitrate of commerce is obtained from the caliche. The composition of caliche is variable as a large number of analyses show.[7] Sodium nitrate comprises from 25 per cent to 50 per cent of the total. Other salts present in greater or lesser quantities are potassium nitrate, sodium chloride, sulphates of sodium, magnesium, and calcium, while traces of several other salts or oxides are also present. Probably the most significant of these is sodium iodide, from which is obtained the iodine of commerce. Insoluble material runs as high as 50 per cent.

The Reserves of Chilean Nitrate.—In view of the vital importance of nitrate to agriculture and to industry, attempts have been made from time to time to estimate the available reserves. Sir William Crookes, in 1898, believed that exhaustion was a matter of a few decades. His knowledge of the fields, however, was limited, and the experience of the industry has shown that his pessimistic forecast was unwarranted. The extremely patchy character of the workable caliche deposits make it unsafe to attach much significance to actual figures of tonnage reserves. "Nevertheless it may be stated at once that the evidence even though it may be somewhat intangible, of the Chilean nitrate reserves being adequate to the world's needs for many years is overwhelming."[8] As a

[6] Clarke, F. W., Data of Geochemistry, Bull. 770, U. S. Geol. Survey, 1924, p. 255.

[7] *Ibid.*, p. 256.

[8] Trade Information Bull. 170, Dept. of Commerce, 1924.

practical matter it is not necessary to enter into an elaborate calculation as to whether there is enough nitrate available to supply the world for a given number of years. In the face of the probable development of nitrogen-fixing processes, the world will be interested in Chile's contribution in a competitive market rather than in the probable date of the exhaustion of supply.

ORGANIZATION OF THE CHILEAN NITRATE INDUSTRY

The nitrate industry in Chile has experienced profound changes from the crude and wasteful modes of production and preparation and indifferent marketing methods to an industry utilizing highly technical production methods and well-organized marketing practices.

The Method of Producing and Marketing.—Caliche is mined by surface methods, using low-power explosives and hand sorting to select material high in nitrate. This product, which contains an average of 16 per cent to 17 per cent of sodium nitrate, is essentially a matrix of insoluble earthy material, which may range from a slimy clay through sand to coarse gravel or pebbles cemented together by a mixture of soluble salts. These salts, except the sodium nitrate, consist principally of sodium chloride (salt) and sodium sulphate but include small quantities of iodides and borates, as well as small quantities of other bases, such as potassium, calcium, and magnesium.

The only method used for recovering the sodium nitrate was based on the relative solubility of sodium nitrate, sodium sulphate and sodium chloride in solutions containing all three of these salts. The technique of this method was devised as early as 1809 and consists fundamentally of the following three successive steps:

1. The selective solution of the salts, particularly the nitrate.
2. The separation of the salts thus dissolved from the insoluble material.
3. The separation, by selective crystallization, of the nitrate from the other salts in the solution.

It so happens that both sodium chloride and sodium nitrate have points of maximum concentration at temperatures well below the boiling point of the solution; in fact, under these conditions sodium chloride has a constantly decreasing saturation point with increasing temperature, whereas sodium sulphate, reaches its maximum concentration at a temperature of about 35° C. Consequently, when a solution saturated at atmospheric temperature with the three principal salts of caliche is heated to the boiling point, or say, to 105° C., in the presence of fresh caliche no further sodium chloride is dissolved and only relatively small amounts of sodium sulphate, whereas large amounts of nitrate are free to enter solution. When this solution is withdrawn from the treated earthy material and allowed to cool, there is a consequent crystallization of sodium nitrate but practically little crystallization of the two other salts. It is on these facts that the method of recovery was based.

The final product contained about 95 per cent of nitrate and small quantities of insoluble material, sodium sulphate, sodium chloride, and moisture.

The process outlined above was fundamentally weak in that it was devised for the treatment of raw material of a very high grade mined in the early days of the industry. The tailings from the process of treatment contain an average of not less than 5 per cent to 6 per cent of nitrate, and consequently, as the average content of the nitrate is from 16 per cent to 17 per cent, the average recovery does not exceed 65 per cent. By combining this loss with the estimated loss in mining (from 15 to 20 per cent), the industry recovered and marketed only about one-half of the original deposit. The monopoly enjoyed by Chile enabled the producers to discount this loss in technical efficiency by fixing a high price for the product.

Marketing Methods.—In addition to the factors of crude-mining methods and inefficient methods of treatment, the industry has been so organized and administered as to operate against economical handling of the commodity. The various producers were organized into a cooperative organization known as the Chilean Nitrate Producers' Association. The Association acted as a general sales agent for its members but was not in business for itself. Its membership consisted of companies and firms, and is also closely associated with the government which appoints four of the eighteen directors. The Association advertised, built up markets, obtained orders, and allocated their filling pro rata to the individual producing members. Before free selling was resumed in April, 1927, the latter were under contract to make no sales except through the Association and this contract was secured by a lien on the title to the properties. Each producer has a quota of sales and assumed responsibility to the Association and the buyer for filling orders allocated to it.

This arrangement of centralized sales had the advantages of controlling production to meet market demands, stabilized prices, decreased profits to middlemen, and eliminated the speculator. It had, however, by its one-price policy enabled the high-cost producers, and the small, inefficient operators to partake in the business, and tended to bring about an excess capacity accompanied by irregularity of operation. Although controlled selling afforded several years of apparent prosperity, the ever-increasing competition of synthetic nitrogen ultimately brought about a depression from which the nitrate fields were rescued only by reversion to free selling early in 1927.

The Tax.—An important feature of the nitrate industry was the export tax levied by the Chilean Government. This constitutes nearly 40 per cent of the revenues of the state and was equal to 60 per cent of the shipping and distributing costs. It has been possible for the Government to collect the large sums involved and to pass this charge on to the consumers, as long as nitrate constituted a natural monopoly.

Post War Readjustments.—The stimulus to the manufacture of nitrogen salts occasioned by the heavy nitrate needs of the World War ultimately brought about a profound reaction in Chile. Although by-product ammonia recovered from coke ovens and gas works supplied some nitrogen and synthetic nitrogen salts were produced on a small scale in Norway, the amounts were not sufficient to disturb the Chilean industry. It was only after the War when the Haber process in Germany and its modified form appeared in France and the United States that the Chilean industry was placed in a critical position. Production in 1926 was 20 per cent less than in the previous year and the decline continued in the first half of 1927. Only a reversion to a policy of free selling in April, 1927, brought about a revival of the industry in the latter half of that year.

In the meantime, technical improvements in production were perfected by the Guggenheim interests which permitted the recovery of higher percentages of nitrogen from the caliche. The Shanks process, it was noted above, recovered only some 50 per cent of the nitrate contained in the raw material. The Guggenheim process will recover regularly about 95 per cent. Moreover, increase in yield is not the only economy claimed. The new process permits large-scale mining methods employing machinery. It is also said to make possible even the profitable reworking of the tailings of old oficinas. From results obtained at Maria Elena plant of the Anglo-Chilean company, it has been demonstrated that under the Guggenheim process ore containing as little as 7 per cent nitrate content can be treated at unit production costs of 40 per cent less than those attained by the plants using the Shanks process and treating ore of 15 per cent or 16 per cent nitrate content.

These changes, in themselves, were not sufficient to assure continued stability to the industry. The formation of a cartel of European producers, in 1929, gave indication of a keen struggle for the world's nitrogen markets. Accordingly, a complete reorganization resulting in the consolidation of all Chilean nitrate interests into one combine was effected in 1930, in a law passed by the Chilean Congress.

This consolidation, Compania de Salitre de Chile, eliminated all other extraction processes in favor of that originated by the Guggenheims and makes this process supreme in the nitrate industry. This substitution will practically double the extraction of nitrogen and greatly extend the reserves. The Guggenheim interests control about 35 per cent of the nitrate properties in Chile, and, under the consolidation arrangement, go into the new enterprise as the most important partner of the Chilean government.

Under the law the Chilean government eliminates in favor of the Chile Nitrate Company and its subsidiaries the export tax on nitrate and iodine amounting to about 30 million dollars a year. The law also makes available to the new company all of the government-owned nitrate lands in Chile. In return the Chilean government received half of the stock of the Chile Nitrate Company and is to be guaranteed a minimum return for 1931, 1932, and 1933, amounting to 22.5 million, 20 million, and 17.5 million dollars. After this transition period, ending with the year 1933, the government will rely upon dividends from its stock and a 6 per cent income tax to compensate it for the loss of revenue resulting from the elimination of the export tax. The law provided that the government-owned shares of the Chile Nitrate Company cannot be sold or pledged.

Actually, the Chilean government expects a full solution of its fiscal problems as a result of the new nitrate combine. By pooling all of the nitrate interests of the country, with itself as 50 per cent stockholder, the government has assured itself, it is believed, of revenues which will far exceed those derived under the export tax.

The reorganization of the Chilean nitrate industry comes about 100 years after the beginning of commercial distribution.

Nitrogen from Coal.—Nitrogen is one of the minor constituents of all soft coals, the amount varying from 0.5 per cent to 2 per cent the average of coals used for coking purposes being about 1.45 per cent.[9] This is about 145 pounds of ammonium sulphate equivalent per ton of coal. An annual output of 500 million tons of coal would contain nearly 35 million of nitrogen as ammonium sulphate, an amount far in excess of all the nitrogen used in the United States for all purposes. Only a small fraction of this nitrogen is recovered, however, which is, from the coal used in the manufacture of by-product coke for metallurgical use and in the manufacture of coal gas. These two industries require about 75 million tons of coal annually, roughly one-sixth of the total coal production. These coke ovens and gas producers are essentially retorts

[9] Curtis, H. A., Coal as a Source of Fertilizer, International Conference on Bituminous Coal, Pittsburgh, Nov., 1926, p. 573.

for the destructive distillation of raw coal. In the former the main product sought is metallurgical coke while in the latter gas is the principal commodity and coke is one of the by-products. In both cases these ovens yield, besides coke and gas, such by-products as tar, light oils, and ammonia. Although the nitrogen of the original coal enters into the coke, the tar and the gas during the coking process, only that portion entering into the gas as ammonia is recovered. The average recovery is about 22.5 pounds or less than one-fifth of the theoretical 145 pounds present.[10] There are considerable variations from this average depending upon the character of the coal used, the kind of coke oven, operating conditions, skill of management, etc. The technical processes of ammonia production do not concern us here. Attention will be confined to the position of by-product ammonia in the nitrogen industry of the United States. The economic conditions surrounding its production may be stated as follows:

1. The output of by-product ammonium sulphate has no relation to the demand for fixed nitrogen. Ammonia is one of the minor products of the coking industry. The output of the coke ovens is determined by the requirements of the iron and steel industry and fluctuates with the fluctuations of this basic industrial metal.

2. The selling price of ammonium sulphate is not determined by the cost of production but follows closely the price of agricultural nitrogen. As late as 1925 this curve was determined by the price of Chile nitrate fixed annually by the Chile Nitrate Producers' Association. This price, each year, is determined by the probable output of by-product and synthetic nitrogen so that, indirectly, these latter materials exert a competitive influence on the level of nitrogen prices. The growing output of synthetic nitrogen is making such inroads on the Chilean nitrate industry, that this material will be of increasing importance in determining the price structure. Under present conditions the cost of nitrogen from coal is less than either Chilean nitrate or synthetic ammonia.

The production of by-product nitrogen will undoubtedly continue to grow due to several causes. The output of pig iron will probably show some increase necessitating a greater output of coke, which will be met by increasing the number of by-product ovens. About 80 per cent of the coke is now supplied from such ovens and this ratio will probably continue. The remaining 20 per cent will continue to be supplied by

[10] Tryon, F. G., and Bennett, H. L., Coke and By-products in 1925, Bureau of Mines, Mineral Resources of the United States, 1925, Pt. II, p. 595.

beehive ovens for the yearly and seasonal fluctuations in the pig-iron industry necessitate the operation of ovens of this type. To attempt to operate by-product ovens during the peak demand would result in a costly maintenance of greater by-product oven capacity than can be used regularly by the iron industry. Moreover, beehive ovens can be started up and shut down from time to time without the great difficulties attending the irregular operation of the costly by-product ovens.

Increase in the use of coal gas as a substitute for water gas, decreasing supplies of natural gas, and the growing use of gas for domestic and industrial purposes will enhance the output of ammonia from gas retort ovens, but quantitative estimates of the expected increases are difficult to make.

SYNTHETIC NITROGEN

Synthetic nitrogen may be defined as an artificial chemical compound made by combining the free nitrogen of the air with one or more other elements. The compounds comprising synthetic nitrogen are many in number and are made by various processes. For a long time only a minor source of commercial nitrogen, the synthetic products jumped into prominence during the War because of the vital necessity of fixed nitrogen in the manufacture of explosives. The War needs have passed but the plants engaged in the manufacture of fixed nitrogen are continuing to maintain a prominent position in the market abroad. The War purpose of the synthetic nitrogen plants was to achieve independence of Chile. Costs of production were secondary and, in this country at least, the government itself undertook the manufacture of nitrogenous products at Muscle Shoals, Ala. When, at the close of the War, the military requirements for nitrogen dropped from about 12,000 tons per month to about 2000 tons per year,[11] the synthetic nitrogen plants faced a situation of either stopping production or capturing part of the fertilizer market. This the European plants are attempting to do, but in America the government-owned nitrate plant, after a brief trial run, lapsed into idleness.

The technical developments in the manufacture of air nitrogen constitute one of the most fascinating series of events in the history of industrial chemistry. There are to-day three commercial processes in operation—the arc, the cyanamid, and the direct synthetic ammonia. "The commercial development of each followed in rather close succession in

[11] Curtis, H. A., Nitrogen Survey, Trade Information Bulletin 226, Bureau of Foreign and Domestic Commerce, 1924, p. 59.

the order named, and each development was, from many points of consideration, an improvement over the preceding development."[12]

The arc process, the simplest of the three, produces nitric oxide by the direct combination in the high temperature of the electric arc of the nitrogen and oxygen of the air. The oxide is then passed into water, forming dilute nitric acid, the primary product of the electric arc. This process had its inception in Norway in 1905 when the plant at Notodden went into operation with a capacity of 2500 horse-power. "Subsequent enlargements brought the capacity of this plant to 40,000 horsepower in 1907, 55,000 horsepower in 1911, and 60,000 horsepower in 1919. In 1911 the operating company, the Norwegian Hydro-Electric Nitrogen Company, started a second works at Rjukan for a consumption of 130,000 horsepower and added a second unit of similar size in 1916."

The high consumption of electrical energy is compelling this process to yield to the direct synthetic ammonia process utilizing hydrogen produced by the electrolysis of water. With the electric power requirements for the fixation of one ton of nitrogen by the arc process, four tons can be fixed by the direct synthetic process, while the plant cost per annual ton of nitrogen is less than half that of the arc process. As a consequence the Norsk-Hydro of Norway is replacing its arc capacity with the direct synthetic ammonia process.

The Cyanamid Process.—In the cyanamid process, nitrogen is fixed by chemical combination with calcium carbide to form calcium cyanamid. This is accomplished by passing pure nitrogen over finely powdered calcium carbide at about 1000° C. "This process requires less than one-fourth the electric energy required in the arc process per unit of nitrogen fixed, and hence its development has not been so strictly limited to those countries having unusually low-priced water power."[13] The raw materials required in this process are coal or coke and limestone.

The steps involved in fixing nitrogen by means of the cyanamid process are as follows:

1. Burning of limestone.
2. Preparation of carbide, using coke and lime.
3. Production of pure nitrogen from the air.
4. Treating carbide with nitrogen to form cyanamid.

[12] Ernst, F. A., Fixed Nitrogen Research Laboratory, Bureau of Soils, Washington, D. C., Atmospheric Nitrogen Fixation, 1902–1927, American Fertilizer, Vol. 66, No. 10, May 14, 1927, p. 21.

[13] Braham, J. M., Nitrogen Survey, Part III, Trade Information Bulletin 240, Bureau of Foreign and Domestic Commerce, 1924, p. 8.

The preparation of the carbide is by far the most expensive step in the process. Burning the limestone, preparing the pure nitrogen and combining it with the calcium carbide are relatively simple and inexpensive operations. Nitrogen must be in a pure state before it can be used in this process, hence it must be separated from the oxygen, carbon dioxide, and water vapor by liquefaction and distillation.

The future of the cyanamid process in this country is somewhat dubious. The principal item of cost, the manufacture of carbide, does not give much promise of being reduced, inasmuch as the process of manufacture has become standardized. Other steps in the process can probably be improved but the possible savings in cost are not enough to warrant large cost savings there. Cyanamid can be used as a raw material for the manufacture of urea and this would soon find wide use as a fertilizer if it could be produced cheaply enough. Up to the present time this is only a hope and not an accomplishment.

The only important producer of cyanamid on the American continent is the American Cyanamid Company with a plant at Niagara Falls, Canada. This plant began with an initial capacity of 5000 tons of cyanamid per year in 1909, and has grown until the production in the year 1925–26 was at the rate of 120,000 tons of cyanamid per year. Within the borders of the United States there is only one cyanamid plant, United States Nitrate Plant No. 2, at Muscle Shoals, Alabama. This plant was erected in 1918 with a rated capacity of 110,000 tons of ammonium nitrate per year. It was placed in operation only a short time before the armistice and after a very brief operation trial during which time it produced about 2000 tons of ammonium nitrate, the plant was closed down and has been maintained in a standby condition up to the present time.

The Synthetic Ammonia Process.—The synthetic ammonia process, the latest of the three commercially developed processes, is the one which gives the most promise of producing fixed nitrogen cheaply. Synthetic ammonia may be described as the product resulting from the artificial combination of free nitrogen and hydrogen gases. The fundamental principle upon which all the synthetic ammonia plants are based is the so-called Haber Process—the direct synthesis of hydrogen and nitrogen under high pressures and temperatures in the presence of a catalyst. These gases combine in a ratio of one part of nitrogen to three parts of hydrogen, by volume. The important agent in carrying out the various steps of the Haber process is coal or coke. The impression still prevails, at least in the popular mind, that electric power is essential to this industry, an impression resulting in all probability from the widespread discussion of the nitrogen fixation plans at Muscle Shoals. The importance of electric power in the synthetic ammonia industry passed in 1912 when the Germans succeeded in producing hydrogen on a commercial scale at the Oppau plant. At the present time more than 80 per cent of the fixed nitrogen is produced by means of fuels—coal, coke, or lignite—and less than 20 per cent is produced by electric power, variously divided among the arc, cyanamid, and electrolytic processes.[14]

There are four distinct steps in the fixation of nitrogen by the Haber Process. These may be enumerated as follows:

1. Preparation of the hydrogen.
2. Preparation of the nitrogen.
3. Synthesis of nitrogen and hydrogen to form ammonia.
4. The conversion of ammonia into a solid suitable for transportation and handling.

The preliminary steps in preparing these two gases in the high degree of purity required for the process constitutes one of the principal items of cost in the process. The production of hydrogen is particularly expensive.

Hydrogen.—Hydrogen does not occur in a free state in nature but in combination principally with oxygen to form water. Several methods for the preparation of hydrogen in commercial quantities are available, such as the electrolytic decomposition of water, separation of hydrogen from water gas, steam-iron process, and the application of steam to lignite or coal.

The production of hydrogen by electrolysis of water is almost ideal for ammonia synthesis because of the high purity of the gas obtained (99.7–99.9 per cent),[15] but the capital cost of a hydrogen plant is high, and the electric power requirement is also large. This process is limited in its use to sources of cheap power supply. A few water-power sites susceptible of low-cost development and not in a position to market their power elsewhere would be useful for this method.

A second process, and one which seems very promising, is the production of hydrogen by blowing steam into a furnace of red-hot coke. The oxidation of the coke releases hydrogen. The Badische Anilin und Soda Fabrik of Germany has developed a method of making hydrogen from lignite or brown coal instead of the more expensive coke.[16]

[14] Jones, L. C., Coal in Relation to the Production of Fixed Nitrogen, Proc. of the International Conference on Bituminous Coal, November 15–17, 1926, Pittsburgh, p. 567.

[15] Braham, J. M., Nitrogen Survey, Part III, Trade Information Bulletin 240, Bureau of Foreign and Domestic Commerce, 1924, p. 17.

[16] Daugherty, W. T., German Chemical Developments in 1927, Trade Information Bulletin 532, Bureau of Foreign and Domestic Commerce, January, 1928, p. 8.

In the United States, hydrogen for the synthetic industry is obtained from coal or water gas.[17]

Nitrogen.—The production of nitrogen from the atmosphere in a form suitable for use in the direct synthesis of ammonia constitutes only a very small percentage of the total cost of fixed nitrogen. There are three methods now employed for nitrogen production: (1) The liquefaction and distillation of air; (2) treatment of a mixture of producer gas, and water gas with steam as in the production of hydrogen. The resulting gas, when purified, contains nitrogen and hydrogen in about the proportion required for ammonia synthesis. This plan is used by the Badische Anilin und Soda Fabrik; (3) burning a mixture of air with hydrogen, thus producing a nitrogen-hydrogen mixture.[18]

Ammonia Preparation.—The two gases, hydrogen and nitrogen, are combined to form ammonia by passing a compressed mixture of the two over a catalyst.[19] The pressures vary from 100 to 900 atmospheres and the temperature from 450° C. to 600° C. Only a part of the gaseous mixture combines with ammonia at each passage over the catalyst and hence the uncombined elements must be returned for further treatment. The ammonia is removed from the mixture by scrubbing or cooling and condensation. Several processes of ammonia production are employed, viz., the Haber-Bosch (German), the Casale (Italian), and the Claude (French). The essential differences among these various processes are those of operating pressures and temperatures. All of these methods yield aqua ammonia or liquid ammonia. These materials, as such, are little in demand but they form the basis of a large number of salts in fertilizers and the chemical industry, as well as for conversion into nitric acid and nitrates. The usual method of preparing if for the fertilizer trade is to absorb the ammonia gas in sulphuric acid and to separate the crystals of ammonium sulphate from the mother liquor. A process in which finely divided gypsum suspended in water is treated with carbon dioxide and ammonia also produces ammonium sulphate. This method was used by the Germans during the war.

Résumé of the Commercial Nitrogen Situation.—The rapid changes in the sources of supply of fixed nitrogen permit only generalized statements since the relative importance of the three important sources of fixed nitrogen may change considerably.

[17] Sherman, M. S., Present Status of By-product Nitrogen, Industrial and Engineering Chemistry, Vol. 20, No. 1, January, 1928, p. 80.

[18] For a detailed description of the manufacture of hydrogen and nitrogen, see Nitrogen Survey, Part III, Trade Information Bulletin 240, of the Bureau of Foreign and Domestic Commerce.

[19] "One of the best catalysts so far discovered is composed of pure iron to which small amounts of aluminum and potassium oxides are added."—H. A. Curtis in Chemistry in Agriculture, p. 87.

The world supply of nitrogen for three years is allotted as follows:[20]

	1926–27, Tons (000)	1927–28, Tons (000)	1928–29, Tons (000)
By-product ammonium sulphate	335	405	414
Synthetic ammonium sulphate	332	404	535
Cyanamid	193	225	231
Calcium nitrate	89	116	150
Other synthetic	146	260	402
Other by-product	44	60	56
Chile nitrate	220	430	540
Total	1364	1900	2328

In the United States, the sources of nitrogen for the year 1929 were as follows:[21]

	Tons
By-product coke ovens and gas works	189,000
Chilean nitrate	160,000
Air nitrogen	84,000
Imports from other sources	36,000

The imports of Chile nitrate, after a decline in 1926, are again increasing, whereas by-product ammonia is showing no increase. The contribution of air nitrogen is still a minor factor, but is showing a rapid increase—from 12,800 tons in 1926 to 18,200 tons (net nitrogen) in 1927, and 84,000 tons in 1928. This industry is concentrated into three groups, the Atmospheric Nitrogen Corporation, Lazote, and Mathieson Alkali Works. The present outlet for synthetic ammonia is in the industrial chemical trade rather than in the fertilizer industry. The cost of synthetic ammonia is not less than 6¢ to 7¢ a pound.[22] At this price it cannot compete with either by-product ammonia or Chilean nitrate, if the producers of these materials, decide to cut prices, an eventuality which would certainly come if a surplus arrives in the supply of agricultural nitrogen. Hitherto the expansion of ammonia in industrial chemical uses has been so great that synthetic ammonia producers have found an outlet for their entire product, especially in the manufacture of nitric acid, nitric oxides, and ammonia for refrigeration.[23]

[20] Chemical and Metallurgical Engineering, Vol. 37, No. 1, January, 1930, p. 28.

[21] Chem. Met. Eng., Vol. 37, No. 1, January, 1930, p. 32.

[22] McBride, R. S., Inter-Industry Competition in Nitrogen, Chem. Met. Engineering, Vol. 35. No. 1, January, 1928, p. 54.

[23] For a summary of the yearly developments in the rapidly changing nitrogen industry, the reader is referred to the Annual Review and Progress Number of Chemical and Metallurgical Engineering, January issue.

CHAPTER XXII

PHOSPHATES

It has been said that "the world knows nothing or its greatest men," and surely a like observation would be true relative to its raw materials. To the man on the street "phosphate rock" may mean nothing; he has, in all probability never heard the term. Yet his future progress and happiness depend to a great extent upon the supply and use of this resource. The essential constituent of phosphate rocks or minerals is phosphorus. There can be no life—either plant or animal—without it. Every living cell of the plant body or animal structure and all the bacterial cells contain phosphorus, which is absolutely essential for their existence and life processes. The plants secure all their phosphorus directly from the soil, while animals secure theirs by consuming either plant or animal tissue. Hence the ultimate source of all phosphorus acid in organic life is the soil.

Phosphate Content of Soils.—Unfortunately, the supply of phosphorus in the soil is not large, and in some soils it is extremely small. Few soils contain as much as one-tenth of 1 per cent of phosphorus and many contain much less than that. An average soil may contain 1200 pounds of phosphorus to plow depth and this is sufficient for not more than fifty 100-bushel crops of corn. Grain raising and direct selling of the product, as is the practice of the farming states of Central United States, most rapidly depletes the phosphorus supply of the soil, for the phosphorus of plants is largely transferred to the seed when the plant ripens. Even with dairy or livestock farming, where the manure is returned to the soil, there is an unavoidable loss of phosphorus from the farm. The prospect of the exhaustion of virgin lands, which are now the main source of supply of wheat, is coming nearer with each year that passes, and consequently fertilizers will play an even more important part in the future than they do at the present time.

Phosphate Reserves.—The supplies of phosphatic materials other than those in the soil, fortunately, are large. These occur as phosphate rock, guano, phosphatic limestone, and in the minerals, apatite and nelsonite. As a by-product of the steel industry, phosphorus is contained in the slag from the basic Bessemer and basic open-hearth furnaces. A considerable quantity of phosphorus is present in the barnyard manure on live stock farms. A ton of this manure of average composition contains approximately five pounds of phosphoric acid. Unfortunately, under present methods of handling, much of this is lost by leaching. Also, a considerable quantity of phosphorus is present in city sewage, but very little of this fertilizer material is recovered under the existing methods of sewage disposal. This loss has been estimated as the equivalent of 1,200,000 tons of high-grade phosphate rock.[1] Phosphate fertilizers are obtained at the present time from rock phosphate, guano, and apatite. Of these three only the first-named is produced in the United States.

Geographical Distribution.—The phosphate reserves of the world are immense. The three great fields are the western American (Idaho, Utah, Wyoming, and Montana), the north African field, and the Russian, each of which is credited with 4 billion tons or more. Smaller deposits are found in southeastern United States, Siberia, Egypt, Spain, and the islands of the Pacific and South Pacific Oceans. The total world reserves of phosphate have been estimated at approximately 16,867,000,000 metric tons of which more than 10 billion are of high grade. Moreover, their wide distribution is such as to be readily accessible to all nations.[2]

The principal producing areas are northern Africa and the United States,[3] which together account for more than 90 per cent of the total production. The principal market for phosphate rock is Europe, which consumed over 5 million tons in 1926. The largest single consuming country is the United States, which annually takes over 3 million tons. The bulk of the European supplies are obtained from the north African fields, which supply about 80 per cent of the total consumption. The American fields export less than a million tons to Europe, and this will probably decline as the north African deposits are further developed and the Florida deposits become exhausted. In the Pacific Ocean production is confined principally to Nauru and Ocean Islands, which ship their product to Australia and New Zealand and Makatea Island, which supplies Japan.

Phosphates of the United States.—The United States is fortunate in possessing a large share of the world's reserve of phosphate rock.

[1] Van Hise, C. R., The Conservation of Natural Resources, p. 325, 1918.

[2] Mansfield, G. R., World Conditions as to Mineral Raw Materials for the Fertilizer Industry, p. 94, 1926.

[3] United States, 3,261,496; Tunisia, 2,568,000; Algeria, 929,333; Morocco, 882,021; Egypt, 232,008—metric tons in 1926. Reported world total for 1926, 8,657,187 metric tons, Mineral Res. of U. S. for 1926, p. 200.

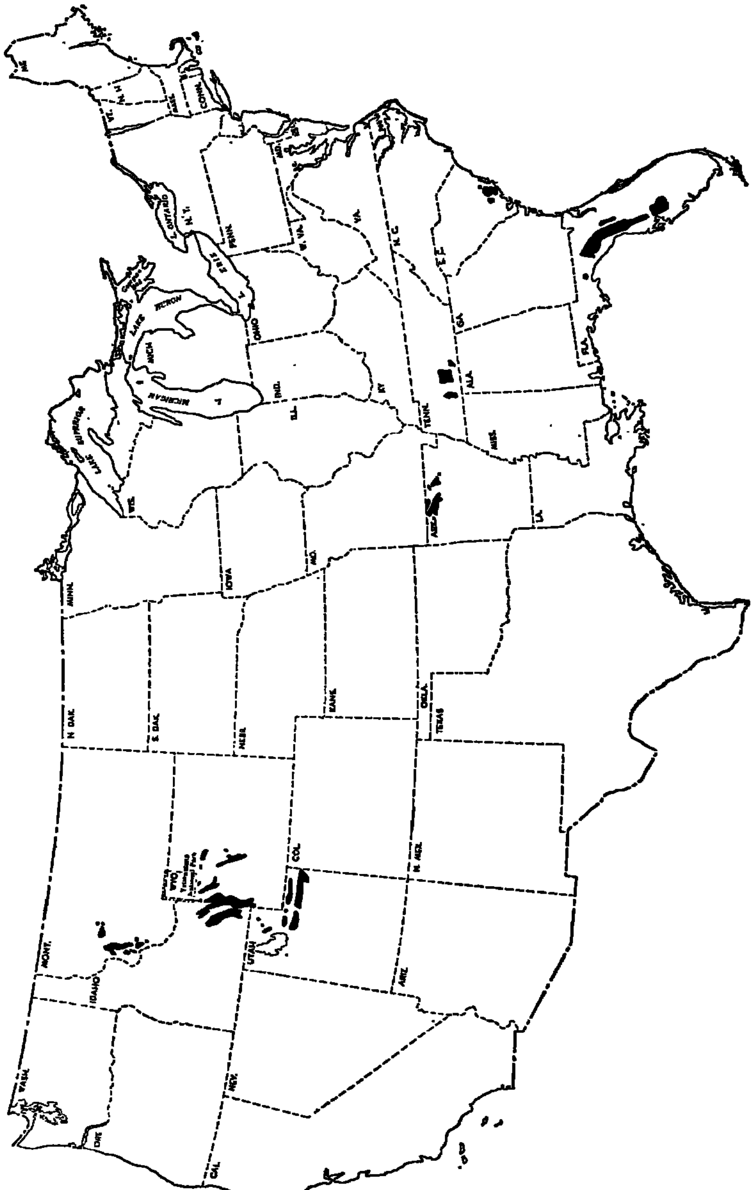

FIG. 8.—PHOSPHATE DEPOSITS OF THE UNITED STATES.

According to Mansfield this country has about 38 per cent of the total world reserves and about 60 per cent of tricalcium phosphate.[4] The deposits are confined very definitely to the southeastern portion of the country and to the Rocky Mountain region (see Fig. 8). The major portion of the reserves are somewhat remote from the present areas of consumption. The distribution of tonnages is as follows:

TABLE XIII *

ESTIMATE OF PHOSPHATE ROCK IN THE UNITED STATES AVAILABLE DECEMBER 31, 1925, IN LONG TONS

Field	Estimated Quantity Available
Eastern Field:	
Arkansas	20,000,000
Florida	291,000,000
Kentucky	878,000
South Carolina	8,788,000
Tennessee	85,500,000
Total	404,166,000
Western Field:	
Idaho	4,997,855,000
Montana	391,323,000
Utah	326,745,000
Wyoming	115,754,000
Total	5,831,677,000
Less approximate quantity mined since 1906	350,000
Total, Western Field	5,831,327,000
Total, Eastern Field	404,166,000
Grand total	6,235,493,000

* Mansfield, G. R., and Girty, G. H., Geography, Geology, and Mineral Resources of Part of Southeastern Idaho, Prof. Paper 152, U. S. Geological Survey, 1927, p. 292.

The figures for the deposits in the southeastern states are based upon a study of Phalen[5] and have been revised from time to time as field surveys were extended.

[4] Roush, G. A., The Mineral Industry in 1926, p. 523.

[5] Phalen, W. C., The Conservation of Phosphate Rock in the United States, Proc. 2nd., Pan-Amer. Sci. Cong., Vol. 8, 1917, pp. 772–806.

The estimates for the western fields exclude many deposits known to exist on lands which have not been fully explored. Hence these estimates may be considered low and the total may be considerably increased when more complete surveys have been made.[6]

Florida.—The leading state in the production of phosphate rock although it possesses only about 5 per cent of the known reserves of the nation. More than 60 per cent of the phosphate rock mined in the United States since 1887 was obtained from Florida deposits. This area supplied not only the domestic markets in the Carolinas, Georgia, and Florida, but also the European consumers. In fact the export market accounted for nearly 50 per cent of the Florida output, until the outbreak of the World War caused a stoppage of overseas movement. The close of the war brought back the market temporarily so that in 1920 a total of 1 million tons was shipped, practically equal to the prewar exports. Since that year there has been a slow decline due to the fact that the two largest consumers, France and Italy, have turned to the North African fields for their needs. Germany, the Netherlands, and the Scandinavian countries continue to purchase the Florida rock.

While deposits of phosphate rock are widely distributed in the northern and central part of Florida, the workable areas are confined to the western side of the peninsula, forming a belt 100 miles in length and variable in width. The deposits are of five general types: (1) hard rock, (2) land pebble rock, (3) river pebble, (4) soft phosphate, and (5) phosphatic marl. Of these only the hard rock and the land pebble types are mined to any extent.

Estimate of the reserves of commercial hard rock phosphates in Florida is exceedingly difficult in view of the fact that no data exist upon which to calculate accurately the area underlain by workable deposits. An estimate by Phalen places the reserve of this rock at 10 million tons.[7]

The land pebble beds are more regular in their occurrence and data about the reserves are more specific. Surveys based upon data obtained from operators in the field and available records indicate that the pebble field contains a minimum of more than 288 million tons of minable phosphates.[8]

Tennessee.—The phosphate deposits of Tennessee rank next in importance to those of Florida among the southeastern fields. Ten-

[6] Mansfield, G. R., Phosphate Rock in 1924, Min. Res. of the United States, Bureau of Mines, p. 88.

[7] Phalen, W. C., The Conservation of Phosphate Rock in the United States, Proc. 2nd Pan-Amer. Sci. Cong., 1917, p. 800.

[8] Mansfield, G. R., Phosphate Rock in 1923, Mineral Resources of the United States, Pt. 2, p. 251.

nessee phosphate rock was first placed on the market in 1894 and in 1929, 35 years later, this state produced approximately 15 per cent of the total marketed in the United States. Since the inception of phosphate mining in this country, in 1867, there has been a marketed production of nearly 80 million tons, of which Tennessee furnished 13 million tons.[9] Most of the Tennessee production goes to the states of the Ohio Valley.

There are three important classes of phosphate rock in the state—the white, the blue, and the brown. The latter is by far the most important of the three, and extensive mining operations on this type are conducted in Maury, Giles, Hickman, Lewis, and Sumner Counties.

In estimating the available quantity of phosphate rock in this field various factors such as irregularity of occurrence, variation in thickness, and probable new discoveries must be considered. Conservative estimates include approximately 4 million tons of brown rock and 80 million tons of blue rock, making a total of 84 million. The mining of the brown rock is done exclusively by stripping, the deposits generally being three or more feet in thickness and occasionally as much as eight or ten feet.[10]

Other Deposits in the Eastern States.—Arkansas. The phosphate deposits of Arkansas extend over a considerable area in the north central part of the State. The quality of the rock is inferior to the Tennessee and Florida phosphates, having less phosphoric acid and more iron oxide and alumina. In some instances the content of these oxides runs so high as to unfit this rock for the manufacture of acid and superphosphate. They can, however, be used in direct application to the soil. Estimates of tonnage in this state are subject to the same difficulties encountered in the blue rock district of Tennessee. The available deposits have been estimated at 20 million tons.[11]

Kentucky.—The phosphate deposits of Kentucky are similar to the brown rocks of Tennessee. Estimates by Phalen place the quantity of rock at one million tons.

Minor deposits of phosphate rock are also found in the Carolinas, Georgia, and Alabama, but these are of no commercial importance.

The Western Deposits.—By far the most extensive deposits of phosphate rock in North America are found in the four western states of Idaho, Montana, Utah, and Wyoming. The phosphate-bearing lands of these western states constitute a Federal reserve created by the

[9] Compiled from reports of the U. S. Geological Survey.

[10] Thirty-second Annual Report of the Minerals of Tennessee, Department of Labor, Bureau of Mines, 1928.

[11] Waggaman, W. H., Jour. Indus. Eng. Chem., June, 1914, p. 464.

Secretary of the Interior in 1908 and comprise 4,541,300 acres. In addition, some phosphate lands are also in private hands.

The deposits are originally sedimentary formations that were laid down at a time when the earth's crust was deeply covered with water. Since their deposition, other sediments have accumulated in overlying beds of thousands of feet in thickness. Deformation of the earth's crust has tilted, folded and, in many instances, broken the phosphate beds. Uplift of the land and subsequent erosion has exposed the edges of many of these beds to the surface. Although the greater portion of the phosphate rock is buried deeply under other formations, their sedimentary character indicates that they maintain at depth the same composition and thickness displayed at the surface. Upon this assumption rest the estimates for the western field. On this basis, Idaho alone, wherein is found the greatest reserve, contains nearly 5 billion long tons. The region is handicapped at present by lack of adequate transportation facilities. This is true for the bulk of the Idaho deposits as well as those of Utah and Wyoming, although for the former there are favorable grades for the construction of branch lines and spur tracks by which the phosphates may be ultimately brought to market. The southern part of the region is accessible from the Oregon Short Line with truck hauls of from 3 to 10 miles. In Montana, however, the deposits are easily accessible to railroads and in close proximity to smelting plants where sulphurous fumes are available for the manufacture of sulphuric acid and acid phosphate.

The western phosphate rock contains a high percentage of tricalcium phosphate and is remarkably low in its content of iron oxide and alumina. The rock possesses the further advantage that it may be shipped directly from the mine and ground and treated with acid without preliminary washing and drying processes which add so much to the cost of production of the eastern phosphates. Some of the companies, however, dry their rock before shipping. On the other hand, the character and mode of occurrence of the rock is such that it can not be mined by open-pit methods. Drifts, tunnels, and shafts, with more or less expensive timbering, are necessary for its successful exploitation.

Status of Western Phosphate Lands.—In Utah, Idaho, Wyoming, and Montana, the bulk of the phosphate rock is on public land, though some has passed into private ownership. The public lands are withdrawn from entry pending their examination and classification. No estimate of the acreage of phosphate land in private ownership is available, but the acreage of public lands withdrawn from entry amounts to 2,263,975 acres. Of this area, 297,585 acres in the four states have been examined in detail and formally classified as phosphate land.

Summary.—The phosphate resources of the United States include a variety of phosphate materials of which only the rock is at present commercially important. This rock occurs in many forms and varies widely in richness and relative abundance in different parts of the country. Some nine phosphate fields may be recognized, but present commercial production is limited to Florida, Tennessee, and the western field. The latter is shut off from the present important market areas because of the long railroad haul and poor transportation facilities.

The Phosphate Industry in the United States.—The chief use of phosphate rock is as a fertilizing agent, either applied directly to the soil or manufactured into acid phosphates or other compounds and included in prepared fertilizers. Small quantities are used in the manufacture of elemental phosphorus. Production is carried on in three areas and is divided as follows: [12]

	Per Cent
Florida	82.9
Tennessee and Kentucky	15.7
Western States	1.4

Florida continues to dominate the southeastern and seaboard market and there is little chance that any other producers, foreign or domestic, can offer effective competition. This security may pass with the exhaustion of the higher grades of rock. The same high grades are helping Florida to maintain a foothold in Europe and to find at least a temporary outlet in the newer markets of South Africa, Australia, and Japan. In view of the aggressiveness of the Moroccan operators and the favor with which their phosphate has been received, the outlook for future trade with Europe is none too bright.

In order to put out a marketable product the phosphate is put through an elaborate washing and screening process, during which, in some instances, two-thirds of the phosphate is washed out upon the dump, with a loss of millions of tons each year.[13] Although no practical plan for prevention of this waste has been devised, recoveries have been slightly increased by the use of finer and more efficient screens and the addition of supplemental washers to rework the tailings. The phosphate recovered under present methods will probably average 25 per cent of the weight of the matrix.[14]

[12] Average of ten years for these districts, 1917–1926, Phosphate Rock in 1926, Mineral Resources of the United States, U. S. Geol. Survey.

[13] Thoenen, J. R., *Mining Hard Rock Phosphates in Florida*, Rock Products, Vol. 29, No. 5, 1926, pp. 51–53.

[14] Burrows, J. T., The Influence of Technology on the Economics of Phosphate Rock, World Conditions as to Mineral Raw Materials for the Fertilizer Industry, National Fertilizer Association, 1927.

In Tennessee the gradual lowering of the grade of rock resulting in a higher cost per unit of phosphoric acid delivered, coupled with a cost of production nearly double that of Florida, serves to confine the outlet to the neighboring states. Over 85 per cent of Tennessee rock is sold in the states of Illinois, Indiana, Ohio, Kentucky, Alabama, Tennessee, Louisiana, and Mississippi.

Production in South Carolina, once relatively important, ceased in 1920.

The Production of Phosphate Fertilizers.—Although there are more than 500 patents relating to phosphate fertilizers, the bulk of the material is put upon the market in three forms, viz., raw rock phosphate, acidulated phosphate, and the so-called "complete fertilizers."

Raw Rock Phosphate.—Phosphate rock as it occurs in nature is not readily soluble in water and in weak acids, and hence the phosphoric acid that it contains is not regarded by fertilizer manufacturers as "available" plant food. Nevertheless, under normal conditions of soil moisture and temperature, it does decompose slowly and enrich the soil. Agricultural experiment stations in many of the states have tested pulverized raw phosphate rock both on limed and unlimed soils. The results of these experiments have led to somewhat differing opinions but in those states in which the tests have been most consistently followed out, the conclusion has been reached that the use of ground, raw phosphate rock is both economical and beneficial for certain crops where a heavy yield the first year is not a necessity. The Illinois Agricultural Experiment Station has been a leader in advocating the use of this material in connection with green or other manures as part of a system of permanent agriculture.[15] Rock phosphate of high grade contains about 32 per cent of phosphoric acid.

Acid Phosphate.—In the manufacture of acid phosphate as now conducted the broken phosphate rock coming from the mines is pulverized by steel rollers in a grinder or mill until from 70 to 90 per cent of it will pass through a 60-mesh screen. After the grinding process, the pulverized rock is conveyed into an acidulator or revolving pan equipped with paddles or stirrers, where it is mixed with an equal portion of sulphuric acid. The principal items of cost in the manufacture of acid phosphate are rock, including the freight on it from the mines to the plant, and the sulphuric acid. Data secured from the Federal Trade Commission for the year 1913 for 19 large plants operated by the seven largest fertilizer companies show that the costs of manufacture vary from $6 to $7 per ton. High-grade acid phosphate contains from 14 per cent to 21 per cent of phosphoric acid

[15] Hopkins, C. G., Soil Fertility and Permanent Agriculture.

depending upon the raw material used in its manufacture. Eighty per cent of the acid phosphate thus manufactured is sold in mixed fertilizers.

The market for acid phosphate is limited to the southeastern states and to those eastern states which can be reached by water transportation. The low intrinsic value of the commodity coupled with the fact that 80 per cent is "filler" means that freight cost per unit of phosphorus ingredient of the fertilizer soon rises to a high proportion of the total cost. This is the most serious handicap of the acid phosphate industry in its efforts to extend the market area and is the incentive toward the production of more concentrated materials.

One of the methods suggested for overcoming the disadvantage of high freight rates is the manufacture of double super-phosphates. The method seems to be particularly appropriate to the Montana deposits. These high-grade "supers" contain about 45 per cent of phosphoric acid in soluble form. The general process of manufacture consists of treating high-grade rock phosphate with sulphuric acid to produce phosphoric acid. The latter acid is then used to treat more raw rock phosphate. This method with some modifications is used by the Anaconda Copper Mining Company.[16]

The Production of Concentrated Phosphate Fertilizers.—The production of soluble phosphates by treatment with sulphuric acid has made possible a cheap fertilizer material where the markets were near to the sources of rock and acid. However, machinery and methods for the manufacture of acid phosphate have about reached the stage of perfection whereby a further reduction in the present low price of the material is hardly to be expected. In fact, it is quite logical to expect the future to bring somewhat higher prices per unit of plant food in acid phosphate as the existing deposits of high-grade rock become depleted.

Freight rates, as noted above, constitute a very important factor in the final price paid for fertilizers by the consumer. This is particularly true in the case of ordinary acid phosphate, for the material usually contains from 80 per cent to 85 per cent of compounds which have no fertilizer value. The solution of this problem, particularly as regards long-distance hauls, depends entirely upon the development of cheap methods for the production of liquid phosphoric acid which may be combined with nitrogen or potash compounds, or may be used to treat further quantities of phosphate rock to produce double super-phosphates. In recent years methods for producing phosphoric acid by volatilization have been receiving a great deal of attention and rather

[16] Mansfield, G. R., Geography, Geology, and Mineral Resources of Part of Southeastern Idaho, Prof. Paper 152, U. S. Geological Survey, 1927, p. 298.

exhaustive investigations have been carried on by the Bureau of Soils.[17] From the data obtained and the progress so far made on the problem it seems probable that this process will be employed to supplement the now almost universally applied method of making water-soluble phosphates by treating the rock with acid. Briefly, the process consists of submitting intimate mixtures of phosphate rock, sand, and coke to the high temperatures attained either in an electric or fuel-fired furnace, thereby driving the phosphoric acid out of the phosphate rock and replacing it by silica, the final product being relatively pure phosphoric acid and silicate of lime. The former is collected in a suitable manner, and the latter is tapped out of the furnace from time to time as a molten slag.[18]

The fundamental principles involved in the pyrolytic production of phosphoric acid are as follows: (1) At high temperatures silica assumes the property of a relatively strong acid and can displace the phosphoric acid of phosphate rock; (2) in the presence of a reducing agent, such as coke, elemental phosphorus is produced and the decomposition of the rock is brought about at considerably lower temperatures. Upon coming in contact with air the elemental phosphorus is burned to phosphorus pentoxide. This process has four advantages which may be briefly summarized as follows:

1. Low-grade and run-of-mine phosphates can be used.
2. Since the furnace process utilizes mine-run material, it is possible to dispense with the costly steps of washing and screening the rock which entails the loss of so much phosphate.
3. The use of sulphuric acid is eliminated.
4. Reduction in bulk will serve to reduce freight rates.

Elements in the Process of Manufacture.—Several years ago the Bureau of Soils became interested in the volatilization process as a possible means for the simultaneous production of liquid phosphoric acid and the use of lower grades of phosphate rock. The first experimental work was carried on by the Bureau with the use of an electric furnace. Preliminary results with this small furnace were sufficiently encouraging to justify experiments on a larger scale and a semi-commercial plant was established at the Arlington Experimental Farm, Virginia. The results of the tests with this plant have demonstrated conclusively that it is feasible to drive off phosphoric acid practically completely from run-of-

[17] Now organized as the Bureau of Chemistry and Soils.

[18] For a report of the Bureau of Soils Investigations see United States Department of Agriculture Bulletin No. 1179, Investigations of the Manufacture of Phosphoric Acid by the Volatilization Process, 1923.

mine phosphates in large scale operations. Based in part upon the success of these experiments, and also upon private research, the Federal Phosphorus Company has installed the electric furnace in its plant at Anniston, Ala., for the commercial production of liquid phosphoric acid. Practically the entire output of the plant is sold to food product manufacturers and for industrial uses. However, some concentrated fertilizer materials are being produced at prices which give promise of soon competing with the ordinary materials now on the market. It is reported that a large portion of the output for industrial and food purposes used in this country is produced at the Anniston plant.

While the electric-furnace process proved to be successful, the high cost of energy militates against its widespread use in competition with the sulphuric acid method of making soluble phosphates. Even when electric energy is available at a price as low as $25 per horsepower year, the actual cost of power is over 70 per cent of the total charge against a ton of phosphoric acid. This cost may be reduced somewhat by improvements in the type of furnace and a better recovery of some of the heat, but it is doubtful if this alone will permit the process to compete with acid phosphate. Moreover, there is little ground for expecting cheaper electric energy through the development of water-power sites. If the initial cost of production of hydro-electric energy in some instances is low, this power will, very likely, be absorbed by industries which can afford to pay considerably more for power to drive machinery than can be paid by most projects using it as a source of high temperatures. This is particularly true of a product like phosphoric acid, which, for fertilizer purposes, must be produced at a very low cost in order to compete with acid phosphate. With this situation in mind, the investigators in the Bureau of Soils undertook to determine if fuel could be substituted for the electric arc. A modified form of blast furnace was developed which proved fairly successful. The batch consisted of a mixture of sand, rock phosphate, and coke. The process is now being developed and used on a commercial scale by a large chemical manufacturing concern in the Central States and seems to be successful.

The early experiments of the Bureau of Soils with the fuel-fired furnace were operated at a temperature of 1600° C., and produced volatilized phosphoric acid and liquid slag. Recent laboratory investigations have demonstrated that phosphoric acid may be volatilized from phosphate rock and coke at temperatures as low as 1200° C. to 1300° C. At this low temperature the mixture does not melt to form a slag but remains in a pulverulent condition, an important feature in fuel economy. This process, if commercially feasible, has several indicated advantages such as a better and more economical utilization of heat and a longer life for the refractory linings of the furnace due to the absence of a molten slag.[19]

Economic Importance of the Process.—It is not to be expected that liquid phosphoric acid, whether produced by the electric or the fuel-fired furnace, will replace or compete seriously in the near future with acid phosphate for fertilizer purposes. The latter will probably always be produced and sold locally at lower prices than the volatilized phosphoric acid, at least until the near-by deposits of rock in Tennessee and Florida are exhausted. The important feature of cheap sources of liquid phosphoric acid for fertilizer purposes lies in the fact that it may be combined with other fertilizer elements, to produce highly concentrated materials, which may be shipped over long distances. This factor is of prime importance in any scheme for the utilization of the western phosphate deposits.

[19] Jacob, K. D., Making Phosphoric Acid by Volatilization, Amer. Fert., October 31, 1925, p. 66; by the same author, Reduction of Tri-Calcium Phosphate by Carbon, Indus. and Eng. Chem., Vol. 20, No. 11, November 1, 1928, pp. 1204–1209.

CHAPTER XXIII

POTASH

THE term "potash" refers strictly to potassium oxide, but it is also employed in a loose manner to embrace the potassium salts in general. The element potassium is an essential to plant growth and belongs to the group of elements whose presence in the soil is limited in quantity and is subject to depletion through cropping. Potash contributes stalk strength and kernel filling to the growing plant. Its combination with other fertilizing materials serves to increase the productivity of the soil in a greater proportion than when used alone.[1] Recent investigations made by the Department of Agriculture show that already the soils in certain sections of the country show a potash "hunger." Some striking experiments made by Dr. Oswald Schreiner, of the Bureau of Plant Industry, in the potato district of Aroostook County, Maine, showed that the addition of moderate amounts of potash doubled the yield of potatoes, and that potash could not be replaced by any other ingredient. The experiments further showed that the amount of potash required to obtain the maximum yield agreed closely to past practice, so that it does not appear that the amount of potash required for growing such vegetables as are included in the term "truck crops" can be reduced. All such vegetables require potash in order to have a texture that will satisfactorily withstand transportation.[2]

Potash, in common with the other fertilizer materials, may be regarded as a labor-saving device, in that it permits a larger yield per acre and hence a greater return per labor unit employed. This factor will not escape the notice of the American farmer very long.

In addition to its function as a plant food, potash is believed to be a specific for the prevention of destructive plant diseases. The relation of potash to the prevention of leaf scorch has been clearly demonstrated

[1] "Potash alone has increased yields only slightly but when added to phosphoric acid has given a larger increase over phosphoric acid alone—29.6 per cent."—Forty Years' Results with Fertilizers, Bull. 175, Pennsylvania State College, Agricultural Experiment Station, 1922, p. 3.

[2] Stockett, A. W., The Potash Situation, Bureau of Mines, War Minerals Investigations, Series No. 2, p. 2, 1918.

through exhaustive researches carried on at the Agricultural and Horticultural Research Station, Long Ashton (University of Bristol),[3] while observations made by Spinks at the Woburn station indicate that both rust and mildew become much less prevalent when potash fertilizers are added.[4] It has also been shown that stripe disease in tomatoes, potato blight, and "die-back" in trees, due to improper nutrition or poor physical condition of the soil, are mitigated by the use of potash.

Although the potash industry is based chiefly on its function in agriculture, the other uses of potassium are wide and diverse. It is essential in the manufacture of the best liquid soap, in some higher-grade cake soaps and in some of the finer grades of glass. It is absolutely essential in the manufacture of certain explosives. Potash now enters largely in the manufacture of matches. The several potash salts find many particular uses in industries so varied as tanning, dyeing, metallurgy, electroplating, and photography. The industrial use of potash, however, requires but a small quantity of the material. Less than 5 per cent is so used, the great bulk of the product going into the fertilizer industry.

American Potash Needs.—The agricultural industry is the principal consumer of potash. The crops for which potash has been specifically used are cotton, tobacco, potatoes, and truck crops. It is, however, essential to other crops as well, and sooner or later our large grain-growing states will have to use potash fertilizers to replenish their soils. According to the Bureau of Soils, a crop of wheat yielding 25 bushels of grain removes 21 pounds of potash from the soil. At this rate a crop of 250 million bushels of wheat, approximately a normal year's exports, would mean a withdrawal from the soil of 100,000 tons of potash.[5] If the straw were returned to the soil this loss would be reduced to 25,000 tons. The present requirements of the United States are about 300,000 tons of potash (K_2O) which is the equivalent of over a million tons of potash-bearing salts, of which the greater part is obtained from France and Germany.[6]

The Franco-German Deposits.—Germany and France possess within their borders the greatest known deposits of soluble potash salts. The German deposits were first discovered and exploited at Stassfurt near the eastern end of the Harz Mountains, in the Prussian

[3] Williams, C. J., Potash in Relation to Plant and Animal Diseases, Fertilizer, Feeding Stuffs, and Farm Supplies Journal, London, reprinted in American Fertilizer of January 3, 1926, p. 36.

[4] Williams, C. J., *ibid.*, p. 37.

[5] Mansfield, G. R., and Boardman, Leona, Potash in 1923, Mineral Resources of the U. S., U. S. Geol. Surv., p. 173.

[6] Coons, A. T., Potash in 1925, Min. Res. of U. S., U. S. Geol. Surv., pp. 213 and 217.

Province of Saxony, and at neighboring Leopoldshall, in what was then the Grand Duchy but is now the State of Anhalt. Subsequent exploration has show that the potash-bearing strata extend to the west along the northern flank of the mountains into Brunswick (Braunschweig), and to the north under the lowlands of the Prussian Province of Hannover and the State of Mecklenburg, and that similar deposits occur along the southern flank of the Harz mountains in Prussian Saxony, in the Thuringian State of Schwarzburg-Sondershausen, and also toward the southwest in Prussian Hesse-Nassau and Thuringian Saxe-Weimar.

There are five generally recognized production centers: (1) The Hannover district, (2) the South Harz district, (3) the Stassfurt district, (4) the Werra-Fulda district, and (5) the Halle-Mansfield district.

Alsatian Deposits.—The French deposits are situated in Alsace just north of Mulhouse, an important manufacturing city in the upper Rhine valley. The productive area is roughly oval, with its greatest dimension about 13 miles extending northeast and southwest.

Reserves.—Estimates of the total potash reserves in Germany vary widely, due in a large measure to lack of definite and accurate information concerning the thickness or even the existence of potash beds in much of the area underlain by the potash-bearing strata. An estimate of 20 billion metric tons of crude salts, which, based upon an average K_2O content of $12\frac{1}{2}$ per cent, would be equivalent to 2500 million tons of "pure potash," was made in 1910 by the Geologische Landesanstalt at Berlin for the potash law commission of the Reichstag.[7] Even these figures were believed to be far too conservative. In 1921 Matignon estimated that the German deposits contained 8 billion metric tons of "pure potash,"[8] while, on the other hand, Ochsenius placed the figure at 3,500,000,000,000 metric tons of crude salts.[9]

The Alsatian deposits are estimated to contain, in all, 1,470,000,000 metric tons of crude potassium salts, which, based on an average content of 22 per cent of K_2O, are equivalent to 350,000,000 short tons of "pure potash." [10]

Unsatisfactory Conditions of Potash Supply.—Since the German and French producers have reached an agreement for a division of the

[7] Friedensberg, F., Kalivorkommen ausserhalb des Deutschen Reichs." Kali Ztschr., Vol. 6, Nov. 15, 1912, p. 570.

[8] Matignon, Camille, Le gisement de potasse alsacien et l'état actuel de son exploitation. (Conference faite a Bruxelles a l'assemblée générale de la société scientifique de Bruxelles.) Revue des questions scientifiques, Louvain, April 20, 1921, pp. 355.

[9] Ochsenius, C., Zentralblatt für die kunstdunger Industrie, Vol. 11, No. 9.

[10] Gale, H. S., The Potash Deposits of Alsace, U. S. Geol. Survey, Bull. 715-Bm, 1920, p. 27.

world's markets the American consumer is virtually subject to the policies of one producing combine.[11] This is, in effect, back to the status of 1914 when nearly all of the potash for agricultural purposes was imported from German and Alsatian mines. During the war period domestic consumption was tremendously stimulated by high prices to which potash rose after the German supply was cut off. Potash was recovered from kelp, from the salines of Nebraska, Utah, and California, from blast-furnace and cement-factory dusts, from various potash-bearing rocks, etc. Since the post war drop in prices and the return of German and Alsatian potash in the world's markets, American production has suffered a decline from a maximum of 208,000 tons of crude salts in 1918 to about 51,000 tons in 1925,[12] followed by increasing production in later years. The principal American producer is the American Potash and Chemical Corporation of Trona, California.

Dangers of Foreign Dependence.—From the point of view of the American potash consumer, the difficulties of dependence upon a foreign monopoly are threefold: First, that the production of the material may be limited arbitrarily, so as to seriously cripple dependent industries; second, the price fixed by the monopoly may be out of economic proportion to the cost of reasonably profitable production, so that an unnecessary burden is thrown on the American consumer; and third, if the material be such a one as is indispensable in time of war, the foreign source may not be accessible in time of most urgent need.

The disastrous effects of the war may be noted when one considers that imports fell from 207,000 tons of potash (K_2O)—approximately 1 million tons of crude salts—to less than 10,000 tons in 1917 and 1918, and prices increased from $35 and $49 a ton for high-grade agricultural salts to $425 a ton for chloride and $350 to $400 a ton for sulphate. American industry was utterly unprepared to meet this emergency. Frantic efforts to establish a domestic industry resulted in an output of nearly 50,000 tons of potash (K_2O), an amount entirely inadequate for normal needs.

Foreign Monopoly in Relation to Prices.—An even more critical situation than that created by the war is the utter dependence of American consumers upon the price policies of the powerful Franco-German monopoly. There is no weapon in the hands of the consumer to compel the European producers to maintain prices at a moderate level.

[11] Hoar, H. M., Potash, Significance of Foreign Control and Economic Need of Domestic Development, Trade Promotion Series 33, Bureau of Foreign and Domestic Commerce, 1926, p. 38.

[12] Roush, G. A., The Mineral Industry in 1925, p. 686.

German Policies before the War.—Prior to the war, when the industry was controlled entirely by the Germans, the price history is one of repeated efforts to lay a heavy charge on the American consumers. The German potash monopoly, effectively established by the law of May 25, 1910, is the result of a long period of experimentation on the part of the industry in an attempt to control output and prices. The value of potash for agriculture and in industry, discovered in 1858 by Franke and von Liebig, stimulated the mining industry so that the period 1865–1872 was marked by a rapid expansion of the industry. Overproduction and the keen competition resulting from the rapid development of the industry induced the larger companies in 1879 to enter into a five-year agreement which limited mining output and determined the distribution of crude salts to various refineries. Although this agreement was loosely formulated and made no attempt to regulate the price of refined products, it was the forerunner of the present strongly centralized and highly organized German Potash Syndicate. By 1883, however, the Aschersleben Kaliwerke, a powerful, newly organized, independent company, was beginning to jeopardize the market of the older concerns, so it was included in a second five-year agreement which superseded the first. During the same year the refineries also entered into a similar agreement which superseded the first. This same year the refineries also entered into a similar agreement to proportion sales orders and fix the price of the refined products.

At the termination of these agreements, in 1888, the first real potash syndicate was formed, with a proposed life of 10 years. Its membership was confined exclusively to mine owners, most of whom were operating their own refineries by this time, but the owners of independent refineries were assured of a supply of raw material if they observed the regulations imposed by the syndicate and did not encourage the establishment of new mines. To eliminate competition and prevent overproduction all sales were regulated by a central agency which assigned orders and determined export prices, the Prussian Minister of Commerce and Industry being given the power to fix domestic prices whenever he deemed it essential to the welfare of German Agriculture. Intensive propaganda also encourage the use of potash in agriculture and other industries, both at home and abroad, resulting in enormously increased sales and much better stabilization of the industry.

This syndicate was renewed, with some reorganization, for a period of three years in 1898 and again for a like time in 1901, but in 1904 the newer mines, which had been taken into the syndicate from time to time, voiced persistent dissatisfaction with the quotas assigned them and almost brought about dissolution of the syndicate. A compromise was effected at the last moment, however, and the syndicate was renewed for six years. The new syndicate was more closely centralized and more intimately related with the Prussian Government, the members were compelled to sell their entire output through the central agency, individual trade-marks were abolished, and large fines were imposed for failure to abide by the regulations.

Potash Law of 1910.—In spite of these precautions, however, dissatisfaction with quota assignments continued to increase, and revival of prosperity in 1906 led to further speculation in the potash industry and the opening of new mines which were strongly opposed to entering the syndicate. Active competition and the lowering of prices on the American market in 1909, particularly by the independent Schmidtmann interests, resulted in a potash war which is one of the outstanding features in the history of the German industry and occasioned serious diplomatic negotiations between the American and German governments. On May 25, 1910, a law was passed which placed all potash production, including that of concerns previously independent, under the absolute control of the Inperial German Government for 15 years.

Among other things, the law of 1910 established a commission to allocate quotas to the various mines, stipulated that no more than one-half of the production of any mine might be exported, provided heavy fines for violations of its provisions, fixed the prices and regulated the sales in foreign markets, and stated that all profits from domestic or foreign sales should be pooled and divided according to the allotted quotas. This law failed, however, in its purpose of checking the increase of new mines and, as a matter of fact, really placed a premium upon new enterprises and the formation of subsidiary companies, due to provisions which guaranteed a quota to any new mine, permitted the transfer of quotas or parts of quotas from one mine to another, and allocated a larger quota to a mine when two or more shafts were being operated. Thus, if a mining company wished to increase its total quota, and hence its share in the profits, it was necessary merely to establish two or three subsidiary companies or to sink and operate additional shafts or mines.

In April, 1911, there were 69 mines in the syndicate and 79 were under construction. A year later 97 mines were prepared to deliver potash and 113 were being opened. In the spring of 1913, 127 mines were operating and 132 being driven. By September, 1915, the number of operating mines had increased to 187 in Germany and 13 in Alsace.

On the other hand, the law was effective in establishing a world monopoly of soluble potash salts and made it possible for German interests to maintain artificial and arbitrary prices and to dictate terms of settlement which foreign consumers, particularly in America, were forced to accept, no matter how onerous they might be.

World War Period.—The German potash industry suffered severely during the World War, partly through increased wages and costs of supplies, but chiefly through the loss of its foreign markets, which had previously consumed nearly one-half of the total production. This important source of income was almost entirely cut off by the embargo of January, 1915, which prohibited the exportation of potash salts, except under special permit and express guarantee that they would not be used for munitions. In spite of conceded increases in domestic selling prices, the proceeds from the greatly reduced volume of sales scarcely covered expenses of upkeep and operation. At the close of the war the situation became acute, because the industry was confronted with serious competition from the Alsatian deposits which had been ceded to France and were no longer under the control of the German monopoly.

The Post War Franco-German Agreement.—The transfer of the Alsatian deposits to France stimulated hopes that the German potash monopoly was finally broken. French interests did, in fact, undertake the development of the Alsatian deposits, worked the mines to capacity and put prices on an economic basis. This, undoubtedly, accounts for the low prices of potash immediately following the war.

This commercial rivalry was not long continued, however. In August, 1924, after several overtures from the Germans, the interests of the two countries succeeded in reaching a compact destined to end competition in the American market. Essentially this agreement fixed the proportion of sales allowed to each of the two nations in the American market and the price to be obtained therefore, France being allotted 37½ per cent and Germany 62½ per cent of the American sales, based on the percentage of deliveries in 1923.

A more recent agreement of May 7, 1927, goes far beyond the previous one in that it regulates the share which each of these two great potash producers will furnish the world's markets. Thus the situation has reached the pre-war status, and we now have Germany and France acting as a monopolistic unit. They supply 95 per cent of the world's potash of which the United States takes about 30 per cent.[13] Both the French and the German producers assert that the object is to prevent a demoralization of the industry through overdevelopment and overproduction, to expedite the marketing of the product, to carry on propaganda for the more extensive use of potash in the present markets, and to cut down selling and overhead charges. There is nothing, how-

[13] Concannon, C. C., Potash in World Trade, Amer. Fert., October 2, 1926, p. 29.

ever, in the present situation to warrant the American farmer in believing that the present level of prices will always be maintained. The monopolistic conditions existing before the war have simply changed from a national to an international character.

Probable Foreign Competitive Sources.—The desirability of establishing competing producers is self-evident, looked at from the American Consumer's viewpoint. The question is, can it be done? Potash deposits of varying grades of richness are found in several localities in the world. Potash deposits of considerable extent are found in Spain, Italy, Poland, Abyssinia (Eretria), and lesser or less-known deposits in Russia, the Netherlands, the Dead Sea, Canada, and Chile.[14] A total of 21 countries other than France and Germany exported potash salts to the United States in 1925, but the aggregate quantity received by this country from these sources was only 15 per cent.[15] Moreover, it is quite likely that a major portion of this 15 per cent originally came from the German and Alsatian mines through Belgium and the Netherlands.

The Spanish deposits are by far the most extensive and best known of the independent foreign supplies. Based on present exploration, these deposits are estimated to contain approximately 2 billion tons of crude salts, equivalent to an available 268 million tons of actual potash.[16] While prospects of ample production to meet Spanish needs are promising, the output of potash has not been sufficient to become a matter of international importance. The ability to compete with Germany and Alsace in the world's markets has not yet been established.

The Italian potash industry is based on the two potash-bearing minerals, leucite and alunite. An English weekly has made the following statement regarding the extraction of potash from leucitic lava:

> The possibility of utilizing the vast beds of leucite in Italy has now entered the stage of practical realization. The Vulcania Company, founded in 1923, has acquired extensive beds of leucite in the volcanic area of Morite Cimino, about 40 miles northeast of Rome. For the separation of the potash salts contained in this leucite, it has erected works which can handle 60,000 tons of rock a year.[17]

The leucitic lavas of the Italian volcanoes are estimated to contain no less than 9 billion tons of potash as K_2O.[18] Some production was reported in 1926. The leucite is crushed and concentrated by an electro-magnetic process to remove the gangue and treated with hydro-

[14] Hoar, H. M., *ibid.*, pp. 59 to 81.

[15] Coons, A. T., Potash in 1925, Min. Res. of U. S., p. 218.

[16] Turrentine, J. W., Potash, A Review, Estimate, and Forecast, 1926, p. 32, John Wiley and Sons.

[17] Chemical Age, London, August 1, 1925.

[18] Hoar, H. M., *ibid.*, p. 69.

chloric acid. The products are potassium chloride, alumina, and silica. Since the potash is a by-product of alumina, its output will be governed by the output of alumina.[19]

Poland.—The potash industry of Poland, while dating back to 1862, is essentially a post-war development. Domestic production, which amounted to about 2500 tons in 1913,[20] rose to 65,000 tons of salts in 1924 and 275,000 tons in 1927. Recent explorations have shown that the potash resources of Poland are far greater than was thought before the war. While much of the territory believed to be potash bearing is still unexplored, the known resources even now aggregate between 18 million and 20 million metric tons of crude salts.[21] Although Poland may not be a factor in international trade in potash, and may never prove to be a source of exportable supply for this essential raw material, nevertheless the exploitation of Polish sources of supply may have a material effect on the strength of the Franco-German monopoly and thus be a matter of vital interest to American potash consumers.

Chile.—"It has long been known that Chilean nitrate, consisting for the most part, and often entirely, of nitrate of sodium, as a rule contains a varying percentage of nitrate of potassium ranging from a trace to over 17 per cent. Practically all of the Chilean nitrate exported contains an appreciable quantity of nitrate of potassium, the amount depending on the section of the pampa from which the caliche is extracted, as in some parts it is richer in potassium than in others. In the past, save in certain instances where the percentage of potassium rose to worthwhile proportions, little importance was attributed to its presence in the caliche. In 1914, however, when the securing of adequate supplies of potassium became a serious problem, the Dupont Nitrate Company began the production of potassium nitrate from the caliche as a by-product in the manufacture of sodium nitrate. This company has now a productive capacity of 10,000 tons of 25 per cent potassium nitrate. The specific process employed by the Dupont Company for the extraction of nitrate has been eminently successful. The details of this process have been generously shared with other Chilean nitrate companies, so that the Chilean fields may become an important source of potassium should the demand therefor be sufficient to justify costs of production. Should all the nitrate producers take up the work of potash recovery, the result would be an annual saving of 120,000 tons of actual potash, which, it is stated, could eventually be

[19] Roush, G. A., The Mineral Industry in 1926, p. 561.

[20] Hoar, H. M., *ibid.*, p. 71.

[21] Allen, R. H., Potash in Poland, Trade Information Bulletin 449, Bureau of Foreign and Domestic Commerce, 1927, p. 4.

raised to 320,000 tons of potash (K_2O) as a by-product of the nitrate industry."[22]

The Dead Sea.—The commercial extraction of potash and other salts from this body of water is receiving serious attention. A report of the British government gives an estimate of two billion tons of potassium chloride, together with large quantities of bromine, salt, gypsum, and calcium and magnesium chloride. A concession for the exploitation of the Dead Sea has recently been granted to a British syndicate. The principal provisions of the proposed concession include the following: The concession shall be for a period of 75 years, and an exclusive concession for the first 25 years. The company will be required to produce a minimum of 1000 tons of potassium chloride of 80 per cent purity, or its equivalent, during the third year of the concession period, rising to 50,000 tons per year after the tenth year.[23]

Summary of Foreign Producers.—Foreign competition with the Franco-German combine is potential and not actual. Although the potash deposits of the world are widespread, and many of these give promise of economic development in the future, only a few of these can be expected eventually to enter the American market, possibly Italy, Spain, Chile, and the Dead Sea. At the present time, however, there seems to be no indication that the European monopoly will be broken by independent foreign competitors.

Possibilities of Domestic Potash Production.—Under the stimulus of war-time prices domestic production of potash from various sources was undertaken. The output in 1917, for example, was obtained from natural brines, alunite, cement and blast furnace dusts, kelp, molasses, and sugar refineries. The alkali-lake region of Nebraska furnished 45 per cent of the output of crude salts.[24]

Production of crude potash rose above the 100,000-ton mark throughout 1918–1920, but, in the fall of 1921, when 34 American fertilizer companies entered into contracts with the German Potash Syndicate and the Alsatian producers to supply all the potash they needed, at prices lower than pre-war figures, the American infant industries were doomed.[25] Their doom was sealed when potash was put on the free list by the tariff law of September 22, 1922. With the exception of the plant of the American Potash and Chemical Corporation at Searles Lake, California, domestic plants produced relatively insignificant

[22] Hoar, H. M., *ibid.*, pp. 78–79.

[23] Dept. of Commerce, Chemical Division, June 3, 1929.

[24] Gale, Hoyt, S., and Hicks, W. B., Potash in 1917, Mineral Resources of the United States, Part II, U. S. Geol. Surv., p. 397.

[25] Mansfield, G. R., Potash in 1922, Mineral Resources of the United States, p. 87.

amounts.[26] However, if the producing industry is small, the United States does not lack in abundance of reserves. Investigations by both the U. S. Geological Survey and the Bureau of Soils disclose domestic resources of the following types:

Salt beds in western Texas and adjacent parts of New Mexico and Oklahoma. Beds of potash are known to be associated with these at a number of widely scattered localities.

Natural brines in California, Utah, Nevada, Nebraska, and Texas.

Insoluble materials such as alunite in Utah, leucite in Wyoming, greensands in New Jersey, and shales in Georgia.

By-product potash from salt and soda works in California and Nevada and from cement mills and blast furnaces in various parts of the country.

Organic sources, such as kelp form the Pacific Coast, molasses and beet-sugar refinery wastes, wool washings, and wood ashes.

Not all of these sources are capable of development in competition with foreign producers, and some of them can supply only small quantities of potash.

Natural Brines.—The only producer of importance is the American Potash and Chemical Corporation at Searles Lake, San Bernardino County, California. This lake, which in reality is a salt-incrusted valley floor, is approximately 12 miles square, and the depth of the salt is 60 to 100 feet, probably averaging about 75 feet in the main part of the deposit. The deposit is in effect a consolidated mass crystallized from an evaporating mother-liquor brine, in which the salts are still immersed. Estimates indicate that this old lake bed contains the equivalent of 20 million tons of actual potash (K_2O) in a saturated brine associated with borax, salt, and sodium sulphate.[27] The proportion of potash in the dried salts is about 7.2 per cent. The output of Searles Lake during 1924 was about 10 per cent of American purchases and in 1929 rose to about 20 per cent. The potash, owing to recently improved methods of extracting, is of excellent quality. The recovery of borax as a by-product is necessary for the profitable operation of the plant, so that the amount of potash that can be produced will depend upon the quantity of borax that can be sold.[28]

The **Nebraska salines** occur in small shallow bodies of water containing varying concentrations of sodium and potassium salts. They are scattered over an area of about 800 square miles and the aggregate of potash deposits are large. The quantities available are difficult to

[26] Mansfield, G. R., and Boardman, Leona, Potash in 1923, Mineral Resources of the United States, p. 175.

[27] Hicks, W. B., Potash in 1918, Mineral Resources of the United States, p. 404.

[28] Teeple, J. E., The Industrial Development of Searles Lake Brines with Equilibrium Data, A. C. S. Monograph No. 49, 1928.

determine. However, it has been estimated by Hicks, who made an examination of the area, that these salt beds might contain the equivalent of several hundred thousands and probably a half million tons of actual potash.[29] The smallness of the individual deposits, however, make it improbable that this resource can be developed except in an emergency. Condra estimates the cost of producing potash in the alkali-lake region at from $20 to $44 per ton, an average of $30 per ton for the crude salts or $120 per ton for potash ($K_2O$). The costs of labor, fuel, and supplies in this region are very high.[30]

Other Salines.—Great Salt Lake and Salduro Marsh, in Utah, which yielded potash during the war and certain lakes in Texas and California that are not yet productive are probably promising sources that could be drawn upon in an emergency.

Alunite deposits of considerable extent are found near Maryvale, Utah, and may prove to be a source of potash if economical methods of extraction can be developed. Possible by-products in the extraction of potassium sulphate are aluminum and sulphuric acid. The production of potash from these sources rose to 600 tons monthly during the war but ceased when prices fell.

The Leucite Hills of Wyoming contain enormous supplies of potash. The success of the Italians in exploiting the leucitic lavas of that country is, therefore, of considerable interest, because of the possible future development of the Wyoming deposits.

Greensand deposits cover large areas in the states of New Jersey, Delaware, and Maryland and are ideally situated from the commercial point of view. According to the Geological Survey they contain enough potash to supply American agriculture for a thousand years.[31] The solution of the problem of extracting potash therefrom, accordingly, might mean the solution of the American potash problem. Profitable production depends upon by-product recovery, and the work has now progressed to the point where all the constituents of the raw material—potash, alumina, iron oxide, and silica—are rendered into valuable commodities by a simple and inexpensive process. A small production was reported by the Electro Company of Odessa, Del.[32]

Recovery of Potash from Cement Mills and Blast Furnaces.—Two manufacturing industries in this country use raw materials containing

[29] Hicks, W. B., Potash in 1918, Mineral Resources of the United States, U. S. Geol. Surv., p. 403.

[30] Condra, G. E., Preliminary Report on the Potash Industry of Nebraska: Nebraska Conservation and Soil Survey Bull. 8, 1918.

[31] Mansfield, G. R., and Boardman, Leona, Mineral Resources of the United States, 1924, p. 43.

[32] Coons, A. T., Potash in 1927, U. S. Bureau of Mines, p. 44.

small amounts of potash silicates, viz., the Portland cement and blast furnace industries. In the process of manufacture the raw materials in both these types of plants are ignited with lime at such temperatures that more or less potash is set free and escapes by volatilization. These two industries are already firmly established and for them the problem becomes one of the successful recovery of the volatilized potash as a by-product.

Potash Recovery in the Cement Industry.—In a study made by Ross, Merz, and Wagner,[33] it was found that, in an average for all plants, for each barrel of cement produced an average of almost 2 pounds of potash is lost. On a basis of an average production of 90 million barrels of cement, the total potash escaping from all cement plants in the country is estimated at 87,000 tons annually.[34] Since these estimates were made, installations have been placed in a number of plants for the recovery of this potash, and in every case the quantity that was found to escape from the kilns closely agreed with the theoretical estimates above.

It should be recognized that the dust from some cement plants is probably too low in potash content to permit profitable recovery, while, in other cases, the richness of the dust is sufficient to warrant the installation of potash recovery apparatus. It is not assumed that the total theoretical loss of 87,000 tons can be recovered.

Potash Recovery in the Blast Furnace.—A study by Merz and Ross[35] of the blast-furnace industry indicates a loss by volatilization of over 80,000 tons of potash annually from all blast furnaces. This is an average of 4.9 pounds per ton of pig iron produced. The quantity escaping from each furnace varies widely due to the varying content of potash in the raw materials used. The greatest loss of an individual plant so far reported is that of the Bethlehem Steel Corporation where the amount escaping was calculated at 17.9 pounds. No doubt, in many of the plants, it will be found that the dust will be too low grade to be used as a source of potash. Furthermore, the cost of installation excludes the possibility of recovery at most small furnaces. However, the situation with respect to plants operating on manganiferous, manganese, southern, or Marquette and Menominee ores should be entirely different. Owing to the relatively high potash content of these ores,

[33] Ross, W. H., Merz, A. R., and Wagner, C. R., The Recovery of Potash as a By-product in the Cement Industry, Bull. 572, U. S. Department of Agriculture, 1917.

[34] Merz, A. R., and Ross, W. H., The Recovery of Potash as a By-product of the Blast Furnace Industry, U. S. Dept. of Agriculture Bulletin 1226, p. 2, 1924.

[35] Merz, A. R., and Ross, W. H., The Recovery of Potash as a By-product in the Blast Furnace Industry, U. S. Dept. of Agriculture Bulletin 1226, March, 1924.

it is possible that the dusts from these plants are richer than the best of the cement dusts. If the proper systems of dust recovery are eventually adopted by the blast furnace industry, these may serve as an important addition to the potash supplies of the country. Two furnaces of the Carnegie Steel Company, Pittsburgh, recovered and sold potash in 1926 and 1927.

Subterranean Potash Beds of Texas and New Mexico.—The discovery of natural potash salts in Texas and New Mexico offers the greatest present hope for American independence of foreign potash. Exploratory work by the Geological Survey indicates that in western Texas and probably in the southeastern part of New Mexico there are vast beds of potash salts within 1200 feet of the surface and extending through wide areas. Some of these sections show large percentages of potash, and it is quite certain, the geologists state, that in this region the nation possesses enormous potash reserves. This section is part of the great Red Beds of southwestern United States, where exists a series of sandstones, shales, limestones, etc., which, through intervals of 1000 feet or more, carry beds of salt estimated to contain 30,000 billion tons of rock salt. This is the greatest known salt field in the world. A number of relatively rich potash beds have been encountered by the drill.[36]

The commercial exploitation of these potash deposits will be governed by the cost of production and delivery to the market as compared with the Franco-German output. Unfortunately, these Texas deposits are far from the centers of consumption on the Atlantic Seaboard and far inland necessitating expensive railroad hauls. It is not likely that they can enter these markets in competition with the German product. However, the ultimate demand for fertilizers in the agricultural areas of the Middle West may permit the building up of a southwestern potash industry which can compete successfully in the markets of the Mississippi valley.

Conclusions.—The agricultural industry in the United States is, at present, dependent upon the Franco-German potash combine for their needed supplies. The establishment of an American potash industry is yet to be realized, but the progress made to date and the results in hand promise that the early exploitation of new sources of potash are highly encouraging. Surveys by the Geological Survey and the Bureau of Soils have disclosed immense reserves of domestic potash. The war emergency stimulated experimentation in the development of many of these resources. The post-war deflation subjected these developments to the most trying economic tests of their feasibility for peace time conditions. With such a background of survey, investigation,

[36] Hoar. H. M., *ibid.*, p. 85, Dept. of Interior, Press Memorandum, March 25, 1929.

and industrial experimentation, the way has been prepared for a constructive attack on the problem of establishing a domestic potash industry. Developments will not be confined to one source but will draw upon several sources and in diverse localities—the greensands of New Jersey, the shales of Georgia, the subterranean salines of Texas and New Mexico, and by-products of cement mills and blast furnaces. Moreover, the American potash industry will be a by-product, or multiple-product industry. The plant at Searles Lake, California, now yields valuable borax as well as potash itself. The greensands of New Jersey can yield ferric oxide, alumina, and activated silica. Alunite can produce alumina and sulphuric acid. Each raw material constitutes a distinct problem. The production of cheap potash will come about, not by the exploitation of a single large deposit but by the erection of relatively small potash plants, located with reference to the agricultural areas to be served, and turning the by-products into marketable commodities. "Only in this way can we hope to effect complete emancipation from the German-French monopoly."[37]

[37] Turrentine, J. W., Some Economic Aspects of Texas Potash, American Fertilizer, March 5, 1927, p. 68.

CHAPTER XXIV

SULPHUR

SULPHUR stands next to coal and iron as one of the most widely used minerals of modern industry. While the quantity of sulphur mined is far less than either coal or iron, its application is so varied and fundamental that it may be considered a major factor in industrial operations. Industries of far-reaching importance such as paper and rubber making, oil refining, steel pickling, textile manufacture, use large quantities of sulphur or sulphuric acid. What is the most important use of sulphur is like asking what is the most important wheel of a machine. It functions as a key material in some phase of practically every manufacturing process.

Sulphur in the Paper Industry—Sulphur enters into the manufacture of paper chiefly in two forms, as a sulphite in the making of sulphite pulp and as sodium sulphate in the manufacture of kraft paper, wrapping paper, and wherever strength is required. The entire pulp and paper industry used, in 1927, 260,000 tons of sulphur equivalent to 20 per cent of the total domestic consumption. These paper-making reagents are prepared by burning elemental sulphur to sulphur dioxide and absorbing in a magnesia-lime solution. The sodium sulphate for the sulphate pulp is obtained as a by-product of the manufacture of hydrochloric acid from common salt and sulphuric acid. The pulp and paper industry is the largest user of sulphur next to the sulphuric acid industry. In fact these two industries use 80 per cent of the entire sulphur output.

While the function of sulphur in many other industries is extremely essential it must be borne in mind that these uses, collectively, are less than the requirements of paper and pulp. One of the chief of these minor outlets for sulphur is the rubber industry. Sulphur is the essential agent in the process of rubber vulcanization. Briefly, it consists of mixing a small percentage of sulphur with the rubber and heating the mixture to a temperature of about 140° C., until the desired properties are obtained. It converts rubber from a substance which could not withstand any great temperature change and which had comparatively little strength to one which will retain its elastic properties over a wide range of temperatures. The rubber manufacturers use about 55,000 tons of sulphur annually. Other uses of sulphur are, as an ingredient in black powder, in agricultural dusts and sprays, paints and varnishes, fine chemicals, wood preservation, and increasing the tensile strength of concrete.[1]

Sulphuric Acid.—The rise of sulphur to its position as a vital industrial raw material is coincident with the rise of sulphuric acid. The combined uses of sulphur for the purposes mentioned above do not equal the quantity used in the making of acid. Sulphuric acid is the most important single commodity in the chemical industry. The raw material for its manufacture are obtained from two sources, native sulphur and pyrite. Nearly half of the six or seven million tons of sulphuric acid produced annually go into the manufacture of phosphatic fertilizers and in the refining of petroleum. The remainder is distributed among the chemical industries, tin plate making, copper reduction, paint, explosives, and rayon manufactures.

The application of sulphuric acid to the fertilizer industry has been treated elsewhere. Its next most important use is in the refining of petroleum. Its consumption by this industry has increased rapidly in recent years. The function of sulphuric acid is to improve the color and odor of oils. Gasoline, for example, requires from one to four pounds of sulphuric acid per barrel, while the lubricating oils require from 20 to 60 pounds per barrel depending upon the color desired. In the chemical industry it is a necessary raw material in by-product coke plants to fix the ammonia liquor into ammonium sulphate. Practically all of the other mineral acids of commerce are made by treating their salts with sulphuric acid.

Sulphuric acid is made by oxidizing sulphur dioxide to sulphur trioxide and absorbing the fumes or gases in water or weak sulphuric acid. The sulphur dioxide is obtained as a by-product of zinc and copper smelting, or by burning iron pyrite or elemental sulphur. The oxidation of the sulphur dioxide is accelerated by means of a catalyst such as platinum. The high cost of this catalyst together with the fact that it is under the political control of two or three nations has stimulated a search for substitute catalyzing agents. The development of a vanadium silicate contact catalyst with a conversion efficiency of 97 per cent to 99 per cent of sulphur dioxide to sulphur trioxide is reported. Besides its decreased cost as compared with platinum, the claim is made that it is not affected by poisons such as hydrochloric acid or arsenic. It operates under substantially the same conditions as the platinum catalyst.[2]

[1] Kobbe, W. H., New Uses of Sulphur in Industry, Ind. and Eng. Chem., Vol. 16, No. 10, pp. 1026–1028.

[2] Nickell, L. F., New Vanadium Catalyst for Sulphuric Acid, Chemical and Metallurgical Engineering, March, 1928, Vol. 35, No. 3, p. 153.

The Sources of Sulphur.—Commercially sulphur is obtained from three sources, native sulphur, pyrite, and the by-product sulphur dioxide of zinc and copper smelting. The latter two sources are used solely for making sulphuric acid.

Native sulphur occurs in the United States, Italy, Japan, Chile, and in minor quantities in Austria, Greece, and France. The Sicilian mines for many years dominated the industry, a fact which can be appreciated that to date Sicily has supplied nearly half of the world's total output of sulphur. The discovery of the sulphur deposits in Louisiana and Texas and the application of the Frasch method of extracting sulphur so altered conditions that Sicilian production declined to a relatively unimportant position. It produces about 15 per cent of the world's total output, whereas the United States' production has risen to over 80 per cent. Moreover, the low production costs of native sulphur, aided by the abnormal demands of war, resulted in an increased use of elemental sulphur for sulphuric acid manufacture in preference to the pyritic sulphur of Spain. This preference has continued after the cessation of hostilities.

Sulphur in the United States.—Although sulphur deposits are known and have been worked in many localities in the United States, the entire present output comes from the large deposits along the Gulf Coast. The world-wide importance of these deposits is due to their peculiar geologic environment which lends itself favorably to the highly efficient method of sulphur recovery employed. The area in Louisiana and Texas where the sulphur is found is underlain with thick deposits of sedimentary rocks lying in a horizontal position except for doming of the rock layers resulting in low surface mounds. The presence of sulphur was discovered accidentally in the course of prospecting for oil. Although the number of domes on the Gulf Coast between the Mississippi and the Rio Grande is large, only five have proven of commercial value for sulphur. The domes consist of a salt core overlaid by a cap rock of anhydrite, gypsum, dolomite, and limestone in which the sulphur occurs. The sulphur sometimes occurs in a pure form but rarely for more than a few feet in thickness. Its common occurrence is scattered through porous cap rock as seams, cavity fillings, impregnations, and disseminations. The sulphur-bearing rock varies in thickness from a few feet up to 250 feet, with a sulphur content from a trace up to 50 per cent. The deposits vary in depth from 300 to 1200 feet. Two companies produce 99 per cent of the sulphur—the Texas Gulf Sulphur Company at Gulf, Texas, and the Freeport Sulphur Company which is carrying on operations at Bryan Mound and Haskins Mound, Texas.

The reserves of sulphur cannot be estimated with the degree of accuracy that is possible in an iron mine or a coal bed. The reserve in the developed mounds is placed at 30 million tons.[3] This does not take into account the possibility of other discoveries in the future. Considerable exploration work has been going on in the Texas coastal plain to discover new deposits, part of this being in connection with explorations and drilling for oil. It is reported that discoveries of large deposits have been made on the Allen dome, about ten miles from Freeport, Tex., and at Palangana dome, San Diego, Tex.[4]

The sulphur industry of Texas owes its importance to the unique system of mining. This is known as the Frash method of mining introduced in 1892 by the Union Sulphur Company and perfected after a decade of trial and experimentation. In this process a pipe is sunk into the sulphur-bearing rocks into which hot water is forced under pressure. The hot water escaping through perforations in the pipe melts the sulphur which is forced upward in another pipe by means of compressed air. The molten sulphur is run into bins and allowed to solidify. The principal cost of mining sulphur is fuel, pipe constituting the second most important item.[5]

The competition between producers prevents any trend toward exorbitant prices. The price of pyrite also exerts an important influence in the price of sulphur. Any unusual rise in the price of brimstone would immediately bring large quantities of pyrite into the market. Furthermore, the Sicilian mines would again enter into active competition and aid in maintaining a moderate price level.

Pyrite.—Pyrite is widely distributed throughout the world, but it occurs at only a few places in quality and quantity sufficient to justify commercial exploitation. Some deposits lie far from points of consumption or are without transportation facilities; other deposits may yet be found in unprospected places. Pyrite is produced in greater or lesser quantities in several of the European countries, in the United States and Canada, and in Japan. Large deposits of it are found in Norway within the Arctic Circle. " One deposit has been described as being a massive lath-shaped intrusive in schist, averaging 75 feet in thickness, with a maximum of 200 feet in thickness and 3000 feet in width, and of unknown length. . . . These deposits were formerly important sources of sulphur before Louisiana and Texas came into the market."[6]

No country, however, has pyrite deposits which can compare with

[3] Mineral Industry for 1923, p. 635.
[4] Mineral Industry for 1926, p. 629.
[5] Chem. Met. Eng., Vol. 32, No. 18, Dec., 1925, p. 919.
[6] Wells, A. E., Mineral Industry in 1926, p. 636.

the vast resources in southwestern Spain, where the deposits are measured in miles instead of feet. Spanish pyrite contains on an average 40 per cent to 50 per cent of sulphur. Practically half of the world's pyrite needs are supplied by the Spanish mines.

The reserves of Spanish pyrite, as estimated by Rubio and Mendizabal, are as follows:[7]

Actual tons	272,730,795
Probable tons	147,561,838
Possible tons	65,000,000
Total	485,292,633

This ore body may be the source of sulphur long after the deposits of brimstone are exhausted.

[7] Rubio, Cesar, and Mendizabal, Joaquin, Pyrite Reserves of the World, 2 Vols., quoted from the Engineering and Mining Journal, Vol. 125, No. 12, March 24, 1928, p. 486.

CHAPTER XXV

CEMENT

THE tonnages of concrete entering yearly in towering skyscrapers, on huge bridges and spans, in vast dams, in miles of roads, in private dwellings, in farm construction, and in hundreds of other ways very nearly justify the application of the term "*The New Stone Age*" to the present century. Portland cement, the active ingredient in concrete construction, has had a rapid rise. Although the beginning of cement use is lost in antiquity, it was not until the end of the third quarter of the nineteenth century that its manufacture was actively taken up in the United States.

The first Portland cement factory in this country was established in 1875 at Wampum, Pa., now the Crescent Portland Cement Company. Clay and limestone were used in the process of manufacture. In the meantime experimental work was being conducted at various localities and, in spite of apparently unfavorable circumstances, the foundations for the present industry were laid. It is natural that an industry, growing up in various localities and using diverse raw materials, would market a product of widely varying characteristics and properties. Such indeed was the case with Portland cement so that in 1898 there were 91 different specifications in use by engineers and builders. This condition was relieved by cooperation among the leading technical societies, the United States Bureau of Standards, and the Portland Cement Association. After much study and the testing of standards in use, a single set of specifications was established in 1911. To-day all Portland cement in this country is manufactured to meet these specifications.

Portland cement may be defined as an intimate mixture of pulverized clay, lime, and small quantities of alumina, silica, and iron oxide burned to incipient fusion and the resulting clinker ground to an impalpable powder. This powder, when mixed with water in proper proportions, will form a mass resembling rock in texture, strength, and durability. Portland cement, when mixed with water, sand, pebbles, or stone in the proper quantities, will bind them together with a grip so tenacious that if a portion of this mass be broken off after it is thoroughly hardened, pieces of stone will be split open, instead of the cement relaxing its hold on them. This mixture of cement and inert materials is called *concrete*.

Economic Characteristics of Cement.—The nature of the cement industry is governed substantially by the characteristics of the product. Since 1912 this has been standardized. Quality, therefore, is eliminated as a competitive factor. The process of manufacture also is well standardized, there is little variation in the organization among the various plants, and there are no patents or trade secrets which might give one firm the advantage over another. The product is bulky and of low intrinsic value so that freight rates may make up an important part of the cost to the consumer. Raw materials for its manufacture are available in many localities so that the market for each mill is practically restricted to its locality. Keen competition exists in the industry both among the cement makers themselves as well as with the manufacturers of brick, lumber, steel, and the other construction materials.

Raw Materials of the Cement Industry.—The raw materials of the cement industry may be grouped in three classes, viz., (1) those entering into the process of manufacture such as the fuels (coal, oil and gas) and fire brick for relining the kilns, (2) the cement-making materials themselves, clay or shale, and lime, and (3) retarders and fluxes such as gypsum, lime chloride, alkalies, and fluorite. To this may be added the cotton and paper used in the making of sacks. The raw materials that go into the manufacture of cement, including coal or equivalent fuel, are roughly twice the weight of the finished product. Coal constitutes one-fourth of the weight of the raw materials used. More than 80 per cent of cement is made with the use of powdered coal as a fuel; the remainder is made with crude oil or natural gas.

Cement Raw Materials.—Ordinary Portland cement contains about 75 per cent of calcium carbonate, 20 per cent of silica, alumina, and iron oxide, and the remaining 5 per cent of unnecessary but unavoidable impurities. All of these materials are extremely abundant in the earth's crust. They may be obtained from limestone, marl, shells, cement rock, shale, etc. The economic conditions surrounding the industry, however, reduce the almost infinite variety of available raw materials to a very few. The necessity of making the mixtures as cheaply as possible prevents the use of a large number of materials whose chemical composition is suitable. Some materials are too scarce; others are too difficult to pulverize; again, others are too far from a market.

A survey of the cement-making deposits of the United States shows an almost inexhaustible supply of material in almost every state of the Union. Limitations upon certain states are due more frequently to the lack of cheap sources of fuel or lack of a local market rather than to a lack of the material itself. The fuel factor is the principal drawback in Maine, New Hampshire, Vermont, South Carolina, while Arkansas, Connecticut, Florida, Idaho, Minnesota, and New Mexico are hampered by a lack of abundance of suitable limestones or clays. The Pacific States are less well supplied with the large limestone beds such as are found east of the Rocky Mountains but have many small deposits sufficient for an industry. The principal drawback in some of the mountain states is not the shortage of cement materials but to a lack of local market.[1]

The producers of cement to-day use four types of materials in the following combinations:

1. Cement rock.
2. A mixture of pure limestone and clay or shale.
3. Marl and clay.
4. Limestone and blast-furnace slag.

Cement rock was one of the first materials used in abundance and until 1910 was the source of more than half of the cement output in the United States. The present output is about 25 per cent of the total for the country. This decline in percentage is due, however, to no diminution of the use of this rock but rather to the growth of the cement industry in other parts of the country. Cement rock is found almost entirely in the famous Lehigh Valley cement district of eastern Pennsylvania although deposits also outcrop in Warren County, New Jersey. This rock is a clayey limestone composed of nearly the ideal mixture of lime and shale for cement-making purposes. The rock is very dark gray and has a slaty fracture. The bed varies from 150 feet to 300 feet in thickness and ranges in composition from about 60 per cent lime and 40 per cent clayey ingredients to 80 per cent lime and 20 per cent clay and other materials. The lower beds of the formation everywhere contain more lime carbonate than the higher ones. It is necessary, therefore, in the Pennsylvania and New Jersey cement plants to mix small amounts of pure limestone with the "low-lime" cement rocks in such proportions as give a proper cement mixture. The advantages of such a combination are evident. Quarrying can be carried on more cheaply than if two distinct materials are used. The rock, as quarried,

[1] Mineral Resources of the United States, Part 2, 1910, published by the U. S. Geological Survey, pp. 488–532, gives a summary of the cement-making materials of the United States. They are also treated in great detail in Bulletin 522 of the U. S. Geol. Survey, 1913, by E. C. Eckel. Both of these publications give extensive references to cement materials in each of the states.

carries little water so that expense of drying them is slight. The material need not be ground to such fineness as in the case of artificially mixed batches. Probably less fuel is necessary. The rapid growth of the cement industry in the first decade of the present century is associated with the use of Lehigh Valley cement rock.

Limestones, Shales, Clays.—The success of the cement industry in eastern Pennsylvania, as well as the rapidly growing demand for this artificial stone, stimulated a search for materials in other sections of the country. Nowhere else was a cement rock found which could be used as nature had deposited it, but shales, clays, and various types of lime carbonates are widely available in some form or other.

THE MANUFACTURE OF CEMENT

The manufacture of Portland cement from quarrying the rock to filling the sack in which the cement is shipped is a thoroughly mechanized process. Heavy and complicated machinery is necessary in the operation of a plant; the cement industry ranks among the highest in capital investment per employee. The method by which the rock is converted into cement divides itself into two processes, the wet and the dry. The wet process is employed where the raw materials are soft, such as chalk or clay. Water is used in the crushing and grinding operations to bring about an intimate mixture of the materials. The pulverized material, called "slurry," is pumped into storage tanks from which it passes to the kilns.

In the dry process the rock passes through crushers and ball mills until a flour-like fineness is reached, so fine in fact that 85 per cent of the resulting powder will pass through a 200-mesh sieve.

Each of these processes consists essentially of four steps, viz., (1) pulverizing the raw materials, (2) burning to clinker, (3) pulverizing the resulting clinker, and (4) sacking the product for shipment. A high temperature is required to properly clinker the material, from 2500° to 3000° F. The principal fuel used is powdered coal although oil and gas are also employed to a limited extent.

Cement is not shipped in barrels; it is sacked, and the sacking of cement is an interesting process. The bags themselves are out of the ordinary in that the tops are tightly wired before being filled and the filling is done through a self-closing vent in the botton. This vent is slipped over a spout or nozzle, a lever is pulled, cement flows into the sack, and it quickly swells much as a toy balloon. When exactly 94 pounds of cement has entered the bag, a scale automatically shuts off the flow. The bags are filled just as fast as the operator can slip them on and off the spout.

The Finished Commodity.—Portland cement as an article of commerce is defined and generally marketed by reference to standard specifications and tests. Those now in force are the result of several years' work of a special committee representing the United States Government, the American Society of Civil Engineers, and the American Society for Testing Materials.[2] They prescribe the chemical limits, the specific gravity, the fineness, the soundness, the time of setting, the tensile strength, how the samples should be treated, and the like. These tests and specifications developed from the importance or necessity of insuring a definite standard of strength and character in a material upon which the stability of great works and the safety of many people depend, and have for many years been the recognized and established means by which Portland cement has been defined, demanded, offered, and sold.

The commodity being thus completely standardized, presents an exceptionally clear-cut example of commercial homogeneity. The character and strength of the commodity as demonstrated by the standard specifications and tests being the basis upon which the engineer has figured, and the thing demanded by the purchaser and user simply being required to meet those specifications regardless of its origin, the product of one manufacturer is commercially identical with the product of any other manufacturer.

The working out of this situation and establishment of a single standard quality specification for cement has had, and must continue to have, many advantages for consumers, producers, and the community as a whole.

The engineer and designer can rely upon getting anywhere the standard quality cement contemplated in his plans.

Concrete can be designed of definite strength and quality.

Simple rules have been made by which even the inexperienced can with care get good concrete.

Greater efficiency in production and lower cost have been made possible through continuous operation on a standard product.

A standard product can always be kept in stock ready for use.

A standard product is more readily acceptable in export trade.

The Cement Industry in the United States.—Although cement was known and employed by the ancients, its large scale use is of recent origin. From a small beginning of 8000 tons in 1880 the production has increased till its present tonnage almost equals that of pig iron as is shown in Table XIV.

[2] United States Government Specifications for Portland cement, Circular 33, Bureau of Standards, 4th Ed., April 25, 1927.

TABLE XIV

Output of Pig Iron and Cement for Specified Years
(In Millions)

Year	Pig Iron (Tons)	Cement (Tons)	Cement (Bbls.)
1880	3.8	.007	42,000
1885	4.0	.028	150,000
1890	9.2	.063	335,500
1895	9.4	.186	990,324
1900	13.8	1.6	8,482,820
1905	22.9	6.6	35,246,812
1910	27.3	14.2	76,549,951
1915	29.9	16.2	85,914,907
1920	36.9	18.7	100,023,245
1925	36.7	30.2	161,658,900
1927	35.0	32.2	171,908,000

Still more significant is the gradual displacement of natural building stones by this artificial stone.

The cement industry is a large-scale industry. By way of comparison with another important construction material, namely, bricks, there are 145 cement plants in the country as compared with 1900 brick establishments, yet the value of the products are nearly the same.[3] The capital invested in the cement industry is one of the highest in the country per worker employed. No other comparably finished product requires so large an investment in proportion to the selling price of the product.

Distribution of Plants.—Mention has been made of the fact that the cement-making materials and cement plants are widely distributed throughout the United States. Establishments are found in all but seventeen states and these are either sparsely populated as in the case of New Mexico, Arizona, Wyoming, and Nevada, or are near important cement-making centers as the New England States. The greatest concentration of plants is found in the district including eastern Pennsylvania, Maryland, and New Jersey. Important producing areas are also found in Michigan, Ohio, Illinois, and Kansas.

Location of a cement plant is not determined by a supply of raw materials only. Other factors of equal importance must be satisfied to prevent the failure of an enterprise, chief of which are market, access to transportation, and sources of cheap fuel.

[3] Commerce Yearbook, 1928, Vol. I, p. 359.

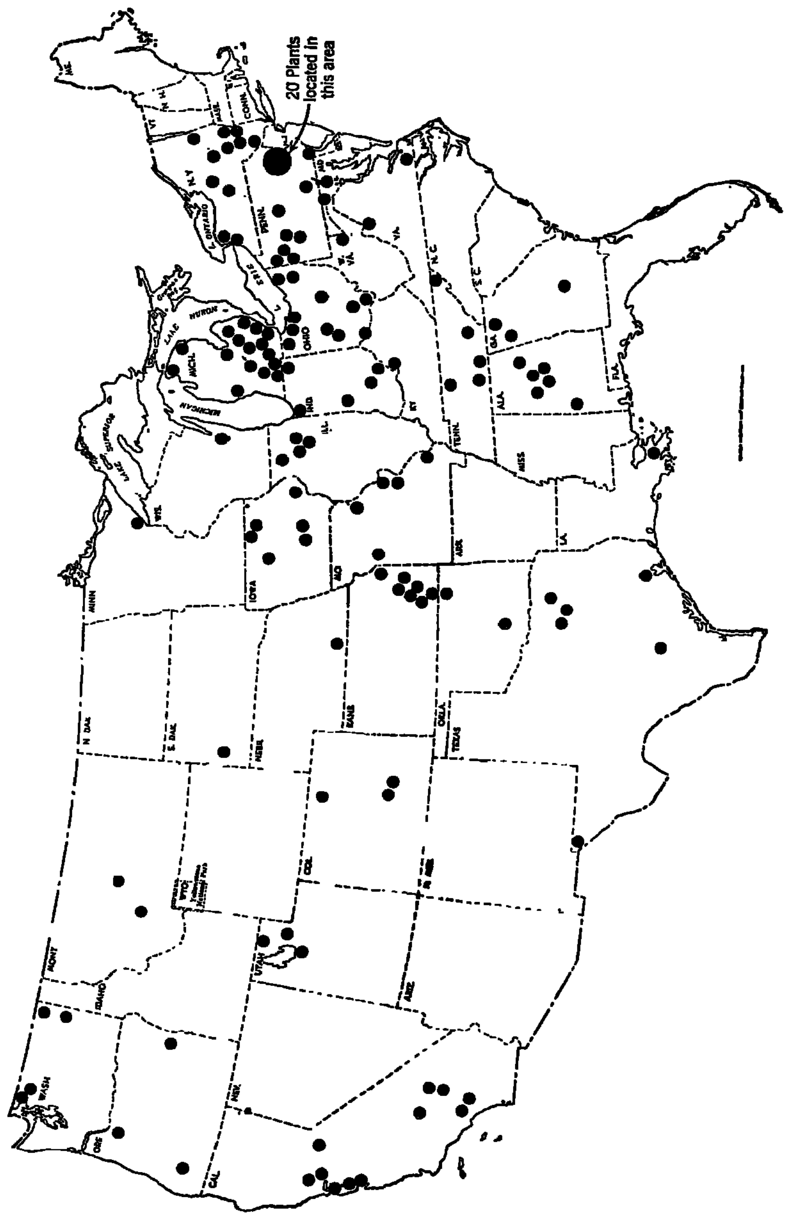

FIG. 9.—LOCATION OF CEMENT PLANTS IN THE UNITED STATES

Market.—It is unwise to attempt the manufacture of cement in localities where the demand for it is limited. A cement plant should have, first, a strong local market area in which there is practically no competition, and, second, easy access to a larger competitive market area. As cement is a very heavy material, transportation charges are relatively high when compared with its value, and on this account the competitive market area is usually restricted. No excellence in limestone or shale can compensate for a small market.

Transportation.—The available market area largely depends on transportation facilities. A high freight rate tends greatly to restrict the field. No plant should be entirely dependent on one railroad line unless the railroad is financially interested with the cement plant. At least two transportation routes should be available, one being preferably a water route.

Fuel.—In general practice, 120 pounds of coal dust is required to burn one barrel of cement. If coal is also used for power, 200 to 300 pounds are required for each barrel of cement. The fuel cost for an average plant is, therefore, 30 to 40 per cent of the total cost of manufacture. A hydro-electric plant may supply the necessary power to operate the machinery, but fuel is necessary for burning the cement. Hence a good fuel supply at reasonable prices is a necessity.

Raw Materials.—The success of any cement-manufacturing enterprise depends largely on the nature, availability, and extent of the raw materials, particularly in areas where competition is keen. The plants that have raw materials that can be quarried, pulverized, and burned at relatively low cost always have an advantage over competitors. On the other hand, if there is a good local market and cheap fuel, a manufacturer may be justified in building a plant where raw materials are of inferior quality.

No plant should be built having less than 20 years' supply of raw material in sight. Each barrel of cement requires approximately 450 pounds of limestone and 150 pounds of clay or shale. Therefore, a plant making 1000 barrels daily will use annually about 66,000 tons of limestone and 22,000 tons of clay or shale. This quantity is equivalent to almost 1 million cubic feet of limestone and 250,000 cubic feet of shale. A 1000-barrel plant should, therefore, have 20 million cubic feet of limestone and 5 million cubic feet of clay or shale available on its property.[4]

Seasonality.—Demand for cement fluctuates markedly with the seasons, varying from 5 million to nearly 20 million barrels per month in the course of the year, the low ebb of demand occurring in December and January. Since most of the cement manufacturing plants do not maintain warehouses to store a product for several months' demand, it follows that production must approximate consumption rather closely. This naturally results in a large idle capacity for a considerable season of the year, and a large needed capacity to take care of peak demand. The manufacturer takes advantage of the slack season in the industry to overhaul the machinery and reline the kilns with refractory brick, a task which is required at frequent intervals in an industry where the rate of depreciation is high.

Competition of Foreign Cement.—The importation of foreign cement, principally Belgian, has increased rapidly. The past six years

[4] Bureau of Mines, Bulletin 160, Mineral Technology 22, pp. 148–149.

(1921–1928) showed an increase from 122,000 barrels to over 3 million barrels. Most of the cement entered Atlantic ports with particularly heavy imports into Tampa, Boston, and Philadelphia. While the quantity imported is but a small percentage of the domestic output—less than 2 per cent—nevertheless, it is offering severe competition to eastern and southeastern mills. Ocean transportation favors Belgian producers since the water rate from Antwerp to Boston is less than the rail rate from the nearest domestic cement plant to this city. The Hawley-Smoot Tariff Bill imposes a duty of 8 cents a barrel.

CHAPTER XXVI

SOME PROBLEMS OF THE MINERAL INDUSTRY

THE character of industrial production is placing an ever-growing emphasis on a supply of raw materials, mineral and non-mineral. The volume of physical production, rising from 100 in 1899 to 261 in 1923, on an index number basis,[1] implies a corresponding increase in the amount of raw materials used. The heaviest demand has fallen on the minerals.[2] The changing character of the relation of raw materials to our industrial economy is an outgrowth of industrial evolution. Although resources, particularly forests, may have been wastefully and lavishly used by the colonists, the inhabitants were so few in number that their aggregate consumption of the seemingly inexhaustible resources of the continent was exceedingly small. The onward march of material progress, familiar to all students of industry, accompanied by a rapid peopling of the country, and manifesting a continual rise in the standard of living, culminated in the early decades of the twentieth century in an enormous per capita demand for material goods. The producers of raw materials, particularly of minerals, were supplying a market which each year, almost without exception, exceeded the year preceding. The favorable conditions under which mineral resources were acquired and exploited under the laws of the nation aided rapid expansion of capacity and output. The unusually large demands created by the World War gave added impetus to expansion. So well did the mining industry meet the demands of the manufacturing industries that the immediate post-war period was marked by overexpansion in coal, oil, copper, zinc, and silver.

The producers, caught in the dilemma of a capacity to produce far beyond the normal needs of industry, attempted heroic measures to find outlets for the products of their mines and to save their profits. The coal people besought Providence to spare them from the calamity of a mild winter, the oil producers urged "more gallonage" by "seeing America first" or aided the tourist by mapping out routes of scenic

[1] Day and Thomas, The Growth of Manufactures, 1899–1923, Census Monograph VIII, p. 34.

[2] See Chapter I, p. 3.

beauty. The copper industry created the Copper and Brass Research Association to find new ways of using copper. The public was importuned to use more of this and that and the other, so that the physical output of industries could be absorbed and expended.

It is well to pause in the midst of this campaign of persuasion and consider its social consequences, for the urge to consume is not confined to the producer of raw materials; it pervades the entire realm of industry and commerce. The object of all this persuasive advertising is clear—to make and sell more goods. The social value of augmented physical output and increased physical consumption may be questioned. To what extent does it release man from drudgery, increase his leisure, multiply his comforts, and add to the amenities of life? When does it reach a point where humans, who have been persuaded to burn more electricity, move more steel over paved roads, listen to more radio concerts, take more distant vacations, eat more candy, smoke more cigarettes, wear more styles of clothing, in short lead a hectic existence in order to keep in motion as much and as many as possible of the material goods that have been produced, become enslaved to material output instead of enjoying the freedom which an intelligent and temperate use of material goods can give?

The intensive, almost frantic, efforts to stimulate the desire of the populace for the consumption of material goods is, in part, the outgrowth of the need to keep the capacity of mine and mill in operation, for idleness is costly. And, as the quantity which must be marketed increases in volume, the difficulties of disposing of it increase; the costs of distribution mount in greater and greater proportion and eventually defeat the very purpose of merchandising—greater profits. Under these circumstances, a sound merchandising policy would dictate a study and survey of the market to ascertain what may be termed the normal consumer demand—the demand which can be satisfied at the most favorable net profit. This policy, necessary in the manufactured goods industry, applies with equal force to the minerals. Whatever may be the specific steps necessary to reconstruct the coal and oil industries, and to a lesser degree, copper, lead, and zinc, the underlying factor is one of a study of the market. The attempt to fit production to the needs and requirements of the mineral market implies control of output, and this is the heart of the problem for the major mineral products. To suggest the problem, however, is simpler than to point out the steps by which the desired goal can be reached. Anyone who has followed the history of the repeated efforts during the past decade in coal, and oil, to achieve a semblance of control in these industries is aware of the difficulties of formulating a workable plan of stabilizing production.

Control of production is a widely inclusive term. It may mean control through monopoly, through an association of producers, through government control and supervision, or even public ownership. Through one or a combination of the methods mentioned above, a workable plan of stabilization must be achieved in order to halt the senseless waste of unneeded goods, with its accompaniment of losses to the producers and investors, losses for which the public must ultimately pay. The plans that have been advanced and in some cases adopted [3] have been discussed previously under the treatment of specific mineral chapters. The inauguration of a satisfactory policy, however, particularly in coal, is still a pious hope and not yet an accomplishment.

The question of control of production leads directly into the broader problem of the conservation of mineral resources. Minerals are wasting assets; a mine once exhausted will not grow another crop of ore. While the farmer and the lumberman can expect, with due care of the soil, to harvest recurring crops of wheat or wood, the time will come when the miner will reach the end of the vein and will read the sign in the rock of "no coal" or "no iron" or "no copper." The nation, however, will require minerals for all time to come for, although the life of man is finite, that of the nation is not. It is true that nations have died in the past, but the peoples of which they were comprised formed new nations. The form of government and the boundaries merely change. In theory, then, the world and its people face a future of diminished or exhausted resources and a limitation of the comforts and conveniences which such a shortage implies.

Since exhaustion, in some minerals at least, is inevitable, the question may well be raised. Why discuss the conservation issue at all? A policy for economizing the use of minerals would simply postpone the inevitable date of exhaustion, a date, moreover, so far distant in the future as to hold no interest for the present generation. The issue of conservation can be justified only on the ground that the living are not absolute lords of the earth's resources but are also stewards for the unborn generations whose well being cannot be totally ignored. If this be granted, conservation becomes established as a definite responsibility and it remains to be determined what is the meaning of the term and what specific steps or policies must be inaugurated to make this meaning effective.

The array of minerals with diverse characteristics and properties, differing degrees of availability and quantity, and differing rates of consumption preclude the possibility of prescribing a simple formula to meet the issue. Some things are more important and some needs more

[3] The achievements of the Copper Institute may be cited as an example.

urgent than others. Some problems require immediate attention while others can be postponed beyond the present generation.

We may assume with fair confidence that, taking the world as a whole, the depletion of natural stores is not yet alarming, although the rate of acceleration, by reason of its local variation, forces into prominence some problems which are national or international in their concern. In view of the increasing acceleration of mineral production, so noticeably a characteristic of the last quarter of a century (see page 3), wise prudence and forethought dictate a taking of stock as an essential initial step. This is indeed being accomplished by such agencies as the U. S. Geological Survey independently or in cooperation with state surveys and an imposing array of information has been gathered. Such a cadastral survey has, in the past, lacked one important feature in that its activities were confined to a study of domestic resources only. The world-wide nature of the mineral industry and the fact of interdependence of nations necessitates a world-wide point of view in making an inventory of known and probable mineral supplies. A true picture of mineral wealth cannot be obtained by surveying a limited area of the earth's surface.

Not even a nation so abundantly endowed as the United States, or the more scattered sections of the earth that are politically united to form the British Empire, contain the full variety of those minerals that are essentially raw materials of their established industries. Even if these two nations—which together produce over two-thirds of the world's minerals—could pool their resources they would still be compelled to obtain from other nations the residual few. Hence the immediate need confronting the nation is a study of the minerals of which there may be a national shortage.

The needs of a people or an industry are met through political action and, in the world as organized to-day, the nation is the unit of such action. The nation must preserve and foster the welfare of its citizens and their activities. In the case of minerals that are needed, and of which no domestic reserve exists, the conditions that will insure an adequate and uninterrupted supply must be established. This can frequently be done without the aid of government. Manufacturing industries may purchase ore reserves in foreign countries or control, through investments, the corporations engaged in the commerce of mineral supply, but the nation must at all times be prepared to protect or defend this interest, or use its diplomatic agencies to prevent an interference with the needs of its industries. The vigilance of such governments as Great Britain in securing control of oil concessions, tin ores, or phosphate islands, is a tribute to the foresight of its statesmen. The growing consciousness among manufacturers of the vital part that minerals play in industry has led to the acquisition by American corporations of such strategic mineral supplies as manganese, iron ore, bauxite, or copper deposits in foreign lands. The preservation of the national interest, however, cannot be pursued without regard to the legitimate interests of neighboring nations. While insuring the domestic position, a country cannot embark upon a policy of depriving a neighbor of needed minerals without inviting trouble or recriminations. International freedom of movement of minerals is a prerequisite to peace.

Minerals and the Tariff.—A policy of domestic mineral conservation cannot ignore the tariff as a factor affecting the situation. The mineral industries have sought tariff protection either for the purpose of excluding imported minerals or of fostering a domestic industry on a competitive basis with foreign supplies. The manganese, cement, and vanadium industries were particularly active during the framing of the Hawley-Smoot Tariff Act of 1929? John L. Lewis, president of the United Mine workers, advocated a tariff on fuel oil to protect the coal industry. Protection of domestic industries is advocated for raw materials as well as for manufactured goods. Without entering into a general discussion of the relation of the tariff to domestic economic well being, the specific issues at stake of a tariff on minerals will be pointed out. A tariff on minerals will, if effective, tend to hasten the exhaustion of the domestic reserve. Moreover, it will also increase the cost of the commodity to the present buyers. Manganese may be cited as an example of the above condition. The tariff on manganese, even if it may eventually succeed in establishing domestic production out of low-grade material, is an extra burden which must be carried by the steel manufacturers. Nor can the domestic manganese producers hope to satisfy the market demand altogether so that imports will always be necessary. The policy of raising the cost of a raw material essential to a large manufacturing industry and at the same time exhaust a reserve which may be of value to succeeding generations, merely to support the interests of a relatively small group, seems to a short-sighted one. Claims for the safeguarding of an investment in a mining enterprise initiated under protected conditions cannot be ignored altogether but, in general, the policy of raising present costs on foreign sources for the privilege of exhausting the domestic supply is unsound. The oil producers also afford an illustration of a group which is seeking escape from the dilemma of over-production by agitating for a tariff on imports of crude or fuel oil. Such a policy would deprive the refineries, particularly on the Atlantic Seaboard, of a cheap source of raw material for the manufacture of oil products, and hasten the depletion of a commodity which is even now being consumed at an alarming rate. The imposition of a tariff as a means of relieving overproduction is attacking the problem from the wrong angle.

The aspect of conservation which goes beyond present national security and considers the future interests of mankind is concerned with questions that are less immediately urgent but, nevertheless, present problems that require thoughtful consideration. The living generation, whether to-day or in the next century, may be expected to take all it needs. Deliberate curtailment of present use for the sake of prolonging the reserve cannot be expected and is not advocated. The duty of the present may be defined in terms of eliminating needless wastes, and initiating research in economy of use. The value of such research is accurately stated by W. R. Whitney: "Search for new knowledge is the insurance for the future of the industries."

An intelligent approach to the formulation of conservation policies necessitates an analysis of the problems that are likely to arise, and a grouping of minerals from the conservationist's viewpoint will aid in giving direction to the discussion. These groups are:

1. Minerals of which there may be an immediate world shortage.
2. Minerals which, once used, are destroyed forever.
3. Minerals which can be used again and again.
4. Minerals which may be substituted by others.
5. Minerals for which there are no substitutes.

Particular attention is directed to the first, second, and fifth groups to determine the extent to which conservational measures are necessary.

Minerals of which there may be immediate world shortage are few in number. The prospect of a declining gold output is admitted, but economies in the use of gold and improvements in the monetary system are expected to offset the diminishing rate of accretion of new gold supplies to the existing stock. The world's visible supply of tin is severely limited, and new discoveries are uncertain. Substitutes for many of the uses of tin are, however, available, such as aluminum or lacquered steel food containers, lead-phosphorus solders, and cadmium as a plating material, and allay somewhat the danger of an impending shortage of this metal. An apparent shortage or approaching exhaustion of a metal hitherto has been met by timely new discoveries either in resources or in technical means of fulfilling the need from some other, and often unexpected, direction. The most resourceful factor against possible shortages hitherto is in scientific research.

The critical minerals, considered from the point of view of long time duration, probably those which are destroyed with use—the energy resources. Although vast in their extent, coal, oil, and gas are also used in immense quantities, and the drain on the world's accumulated store is a significant one. Their importance is augmented when one considers that they can be, in effect, substituted for the metals. The exhaustion of high-grade metalliferous deposits can be followed by exploitation of low-grade ores whose reduction is accomplished by using more fuel per ton for smelting. In this sense coal may be considered as a substitute for iron or copper. The wasteful use of coal is being eliminated, however, not as a conservation measure *per se*, but because science and technology are seeking greater efficiencies in the utilization of the energy content of coal. Thus, improved practices in the economy of coal utilization automatically tend to lengthen the life of the reserve. The date at which fuel exhaustion is likely to occur is so remote that the present cannot concern itself with this problem.

Certain minerals perform a function for which no substitute exists or can be developed. This statement, unless interpreted, might be considered wide enough to include the entire array of mineral resources upon which the existing industrial structure rests. But we can imagine other civilizations succeeding the present in which industrial minerals play a small part. A return to a crop civilization, for instance, is not inconceivable. The minerals in question, in this instance, are the plant food elements. No form of magic can induce plants to substitute one mineral for another, or to live without one of the ten elements of which they are made. Hence, a continuing mineral plant food supply is a prerequisite to continued life on the earth. Fortunately the supply of critical plant food elements—nitrogen, phosphorus, potash, and sulphur—are so abundant that the dangers of a shortage are remote. Moreover, a careful agricultural economy can reclaim and reuse again and again at least a portion of these minerals.

The world's store of minerals need cause no immediate concern or necessitate drastic measures of economy or conservation. The duty of the present to the future is fulfilled if it devotes part of its energy and learning toward research in extending the uses and services of metals and minerals and increases the effectiveness of their services by instituting economies of use.

SOME INTERNATIONAL ASPECTS OF THE MINERAL INDUSTRY

The world scope of the mineral industry has been stressed again and again in the foregoing pages and it is only natural that international trade in mineral products is accompanied by problems involving the conflicting interests of the countries of the world. Nations have in times past fought for fertile lands, strategic waterways, for trade privileges as well as to satisfy the whims of sovereigns. In modern times, the stake of war has included, among other objects, a desire for control of mineral resources. The political boundaries of the nations, originally delimited on considerations dominantly agricultural in origin, have now no natural relation to the distribution of their minerals, which are nevertheless essential for the maintenance of industries in peace time as well as for the requirements of defense.

The inventions of Bessemer, open-hearth, and alloy steels in the latter part of the previous century brought to an end the period of national economic isolation. From this time on no nation could be self-contained; a new era of national interdependence was inaugurated, but the extent and significance of the change was not consciously realized by public leaders until 1914, when it was found that the developments of peace had fundamentally altered the requirements for war.

The World War was fought above the coal and iron mines of France, Belgium, Luxemburg, and the Lorraine. The aftermath of the war was a succession of conferences, agreements, treaties and conversations, in which the question of control of mineral resources figured prominently. These conferences were but a recognition of the fact that the unequal geographic distribution and divided political control of mineral resources form a background of a continued potential menace to the maintenance of peace. The possibilities of international dispute, arising from the discovery, development, transportation, and marketing of mineral resources, has been recognized by men prominent in the mining and metallurgical societies of America and, in 1921, a committee was appointed to formulate a statement of elemental considerations or principles upon which international agreements in the administration of natural resources should be based. This committee prepared a general report in 1921 together with reports on specific minerals, all of which have been gathered in a general statement.[4] This chapter will summarize the findings of the committee with the aim of presenting the opinion of a group who may be considered competent and judicial authorities on the subject of the international mineral problem. The text will contain the conclusions of the committee together with supplementary data bearing on each topic that has been obtained from other studies bearing on the general problem of international mineral relations.

[4] International Control of Minerals. Published jointly by the American Society of Mining and Metallurgical Engineers and the Mining and Metallurgical Society of America, New York, 1921 and 1925.

1. International Mineral Movements are Necessary Consequences of Their Geographic Distribution.

Mineral resources are wasting assets fixed geographically by nature, and change in this geographic distribution is not within our power. Some kinds of minerals are so widely distributed that nearly all countries have adequate supplies within their own boundaries or near at hand. Other minerals are so distributed that some parts of the world have a surplus and others a deficiency. No country is entirely self-sufficing in regard to either supplies or markets for all mineral commodities; in every country certain minerals are available in excess for export, while others are deficient and must be imported either in crude or manufactured forms. International exchange of minerals cannot be avoided if all parts of the world are to be supplied with needed materials. The general nature and location of the fixed channels of international mineral exchange are not matters of conjecture; they are capable of reasonably definite statement.

2. International Movement of Minerals Cannot be Stopped by Enactment.

The necessary international movements of minerals may be aided or hindered by bonuses, preferential duties, tariffs, and embargoes. These measures may be locally and temporarily desirable for a great variety of reasons, but in general it is our belief that in the long run, measures of this kind, aimed at the ultimate closing or diversion of the main international channels determined by nature, are doomed to failure, and that the effort to apply them will demand needless readjustment involving much unnecessary friction in international relations as well as in the orderly development of the mineral industry. When, for instance, it is proposed by tariff to foster an infant mineral industry, the geologic facts of the situation should be squarely faced to make sure that these controlling facts make such a course possible; otherwise there may be vast and useless expenditure of human energy in attempting to develop certain kinds of mineral resources in parts of the world where they are not present in sufficient abundance to be worthy of development. Mineral resources cannot be created by legislation.

Just as it is futile to attempt to make each state in the union self-supporting in regard to all minerals, so the effort to make each country independent of others is rendered impossible by the fact that nature has not distributed her resources in this fashion. Specialization of effort on particular minerals for particular localities seems essential to the conservation of human energy and to the most efficient utilization of nature's resources. To illustrate, if the distribution of raw materials is such that the United States can specialize on the production and export of copper, iron, and steel, and can do this with high efficiency, it seems hardly desirable that it should devote any large amount of effort to the development of its entirely inadequate tin and nickel supplies, which other parts of the world can produce more efficiently.

3. Minerals Should be Concentrated Near the Source of Supply, with Limitations.

In the interest of reduction of bulk and efficiency of transportation, the concentration, refining, and fabrication of minerals near sources of supply should be encouraged wherever conditions permit. Countries fortunate enough to possess large supplies of a needed mineral, deficient elsewhere in the world, are entitled to the advantages that may come from the conversion and fabrication of raw materials, unless local conditions make this possible only at excessive cost. Coal is the chief energy resource required for this work, and experience has shown that many minerals can be utilized with greater efficiency near sources of coal than near the sources of the minerals. With this consideration in mind, we do not favor the application of government measures of aid or restriction which attempt to establish a local smelting or fabricating industry where the supplies of raw materials, including coal, are such that the cost is excessive and efficiency low compared with more favored localities. We recognize as a qualifying factor the conditions of shipping which sometimes make it cheap and efficient to carry crude ores as a means of securing proper combination cargoes, and as a means of balancing local import and export requirements.

Other qualifications enter in the case of specific minerals. For example, antimony, which is very easily reduced, is economically converted into regulus (metal) in China where labor is cheap, whereas in Bolivia, where fuel is at a premium, the natural movement seems to be shipping the crude ore or an intermediate product.

Local smelting is not applicable to chrome, for the reason that it would mean the uneconomic duplication of manufacturing plants already in existence in the chief consuming countries, and so far as ferro-chrome is concerned, is a great increase instead of decrease in cost of freight.

Tin presents an example where the ore, whose average content is not over one pound of metal to a cubic yard of ore must be concentrated locally. As regards smelting, the case is different. The average tin concentrate runs about 70 per cent metallic tin. Its transportation, therefore, involves the movement of 30 per cent waste material. There are, however, many instances where the advantages of such a movement outweigh the added transportation cost. The three principal factors leading to this movement are as follows:

1. Some of the producing countries are wholly or partly lacking in fuel. This applies particularly to Bolivia, which has no fuel at all and sends its ores abroad for smelting.

2. There are certain smelting advantages to be gained by mixing impure ores with pure ores, instead of smelting the two separately. Nigerian concentrates, for instance, which are considered pure, are moved to England, and there mixed with part of the ores from Bolivia, which are relatively impure.

3. In certain sections it is more advantageous, from an investment viewpoint, to handle the concentrates from a large area at a single central smelter, than to build a number of small smelters at individual mines, even though a considerable movement is involved. This applies particularly to the Far East, where the Straits smelters handle not only the production from the adjoining Federated Malay States, but treat also most of the Siamese, and part of the Dutch East Indian outputs.

As regards fabrication near sources of supply, it has already been shown that tin, which is necessarily used by the industrial nations, must be produced in countries in which tin-consuming industries cannot well be established. Fabrication near source of supply is therefore seldom possible.[5]

FREEDOM OF EXPLORATION IS ESSENTIAL

The exploration and development of mineral resources are continuously necessary to replenish ore reserves depleted by production. The present century has witnessed a greater consumption of mineral resources than has taken place in all previous history. Here in the United States the per capita consumption of minerals has multiplied ten times in only forty years. The problem of freedom of replenishment is not incidental, but of basic importance to the prosperity of the greatly magnified mineral industry which can be easily foreseen for the future. Any restrictions, national or international, which interfere with the necessary searching of the earth are in principle undesirable. We recognize the necessity and economic justification, during the early exploration stage and particularly in the case of petroleum, of rights covering large areas in order to induce and justify the expenditures necessary for careful exploration work in new regions. Where such concessions are safeguarded by the stipulation that within a limited period of say three to five years, the holder must select for retention a small percentage of the original exploration area, the result is development without exclusion. Exclusive concessions on large areas without such a reduction factor are economically unsound.

We believe that the aid and supervision of governments may be desirable in connection with exploration work, so far as they do not destroy the opportunity for private effort, but we further believe that government agencies cannot be substituted in this field for private initiative, except at the expense of elasticity and variety of attack essential to the adequate solution of the complex problems of mineral development, and especially of mineral discovery.

In regard to this necessary activity of exploration we stand for equal opportunity and the open door—national and international. Equal opportunity and the open door are considered as implying, among other things, that, except under conditions of national crisis, there shall be no restrictions on the issuance of mining licenses and concessions to foreigners or the transfer of concessions to foreigners; and that there be no restrictions on the nationality of the shareholders, managers, or directors in companies owning mining and exploration rights and concessions, allowing thereby the free purchase and acquisition by individuals of any nationality. The right of nations to control their own natural resources in times of war is of course paramount. There may be other special and local circumstances which might make such control desirable in times of peace. For the most part, however, all large mineral operations are by incorporated companies, and the company being a creature of the state, the state may and usually does define very exactly its right and powers and in this way protects its own interest.

[5] Two opposing tendencies are noticeable in this connection: (*a*) an increase in local legislation to require smelting or fabrication near the sources of supply, even though at a higher cost. An illustration of this is the Brazilian law requiring that 5 per cent of the iron ore mined must be smelted domestically. This requires the importation of coke, a procedure of doubtful economy. Or one may cite the British law requiring all ore mined in the British Empire to be smelted in British possessions. This situation is opposed by the tendency of consuming areas, partly because of the greater financial power, to carry materials, which have been concentrated, to the industrial centers for refining.

Where backward countries possess important mineral supplies needed by the world we can see no escape from the conclusion, whatever the ethical merits of the case, that demand will make itself felt through political pressure of other countries. In such cases we favor joint action by governments to secure equal opportunities for all nationals. If circumstances require that pressure be brought by one government the end to be sought should be the opening up of the territory not only to the government bringing the pressure for its exclusive benefit, but to all nationals. Disregard of this principle has been the cause of much international friction.

PROBLEMS OF THE UNITED STATES

The large share of the world's minerals required by the United States necessitates a considerable importation from foreign countries. The minerals for which the United States must depend almost entirely on other countries are tin, nickel, platinum, and metals of the platinum group; minerals for which this country will depend on foreign sources for a considerable fraction of the supply are antimony, vanadium, zirconium, mica, monazite, graphite, asbestos, ball clay and kaolin, chalk, cobalt, naxos emery, and grinding pebbles.

The fabricating industries of the United States are interested in securing an uninterrupted flow of minerals into consuming centers. This can be accomplished to a degree through the purchase and exploitation of ore reserves by corporate interests of the United States. Thus, the steel industry owns not only iron ore reserves in foreign countries but also supplies of ferro-alloy minerals. Similarly, corporations have gone abroad to acquire oil lands, copper deposits, nitrate fields, bauxite, etc. Such arrangements are sufficient as long as the world is at peace or the various nations do not enact legislation hampering the movement of minerals. Against these latter two contingencies the commercial ownership of mines can give no assurance of a continued and uninterrupted supply. This can only be secured, if at all through the medium of treaties, or international agreements.

With respect to certain minerals used in minor tonnages, it has been suggested that reserves of stock be accumulated in peace time to guard against contingencies which would upset the normal flow of mineral supplies. This has been urged in the case of manganese.[6]

The international conservation of mineral supplies whose visible reserves are limited and which can be increased by means of improved mining methods, standardization of specifications, or otherwise, should

[6] International Control of Minerals, Report of the Committee of the Mining and Metallurgical Society, 1925, p. 85.

receive the cooperation of the United States government wherever opportunity offers.[7]

THE LITERATURE ON MINERALS

The importance of the minerals to modern industry has been observed by various writers in the United States whose authority in the field is recognized. N. S. Shaler, in "Man and the Earth" (1905), devotes a part of the discussion to the significance of minerals. Later contributors whose works are suggested for reading are C. K. Leith, "The Economic Aspects of Geology (1921); George Otis Smith, "The Strategy of Minerals" (1920); J. E. Spurr, "Political and Commercial Geology" (1920); E. C. Eckel, "Coal, Iron, and War" (1921); Gilbert and Pogue, "America's Power Resources" (1921); and H. Foster Bain, "Ores and Industries of the Far East" (1927).

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